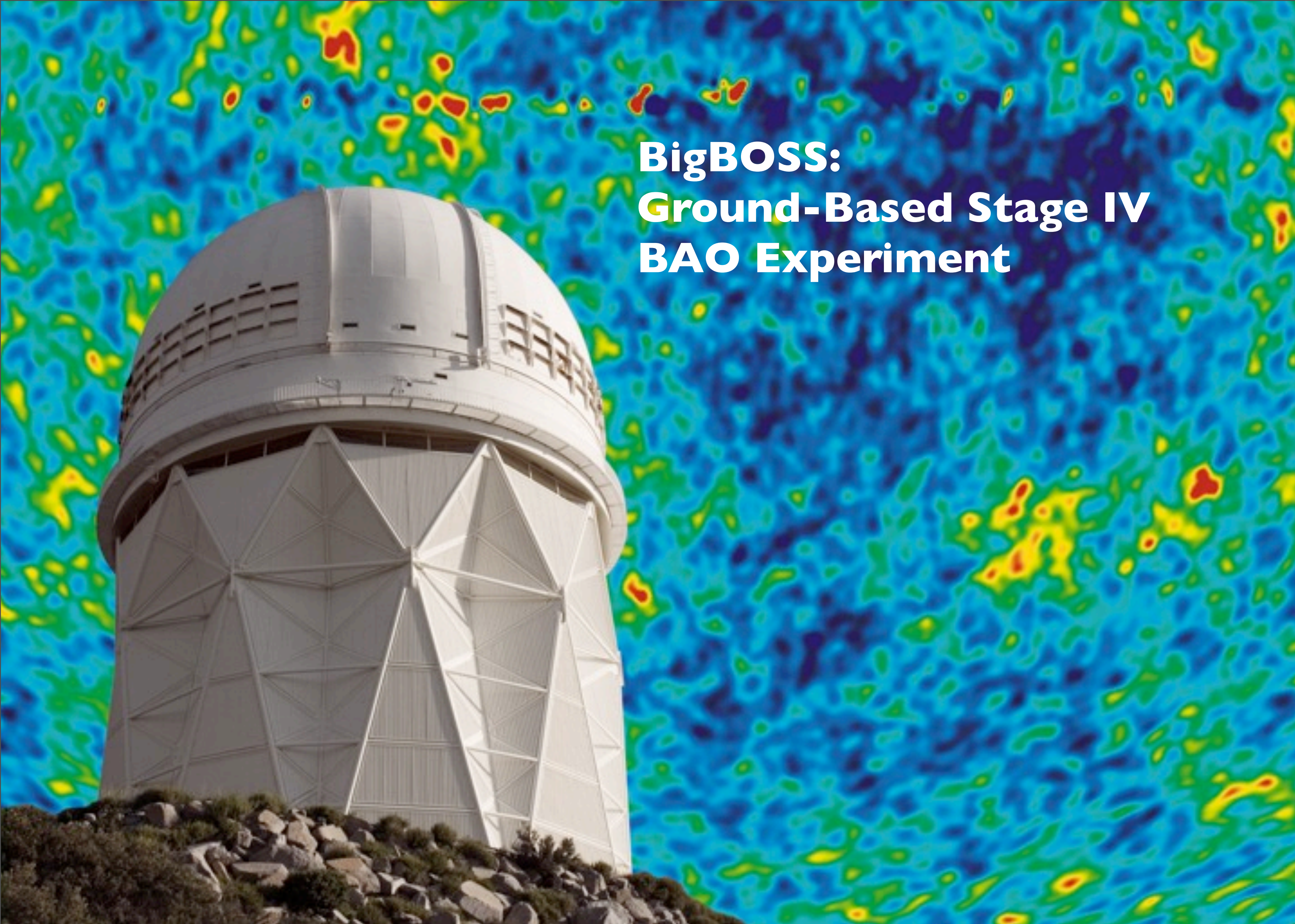
BigBOSS: Ground-Based Stage IV BAO Experiment



Why map the sky?

Test the standard model

Quantum fluctuations -- early Universe permitted because $\Delta E \Delta t < \hbar$
Early Universe inflation by 10^{55}
Leads to scale-free fluctuations
Gravitation growth of structure
(Einstein gravity)

N-body simulation credit: C4 collaboration, Thaker & Couchman

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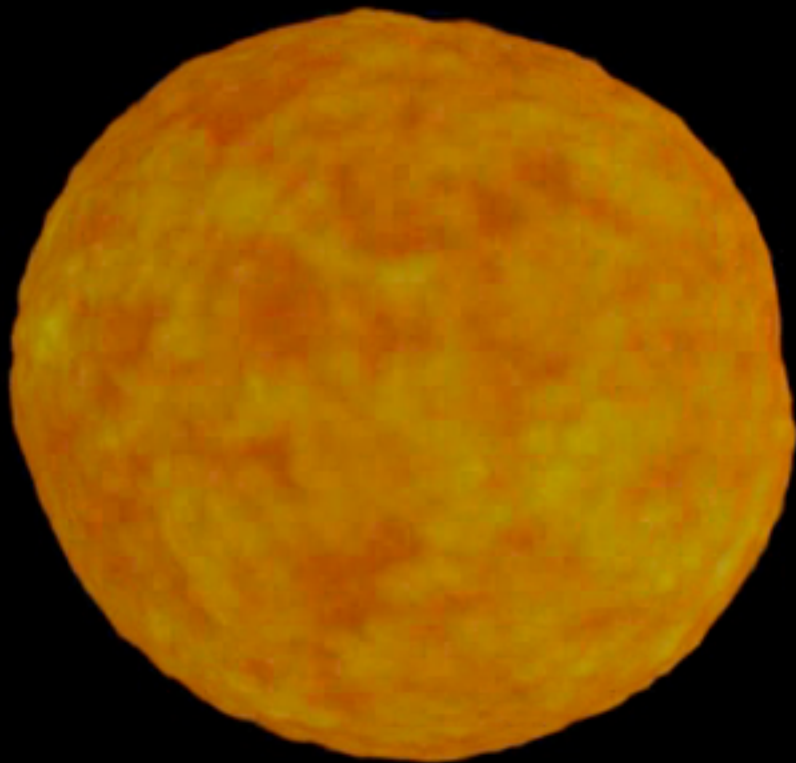

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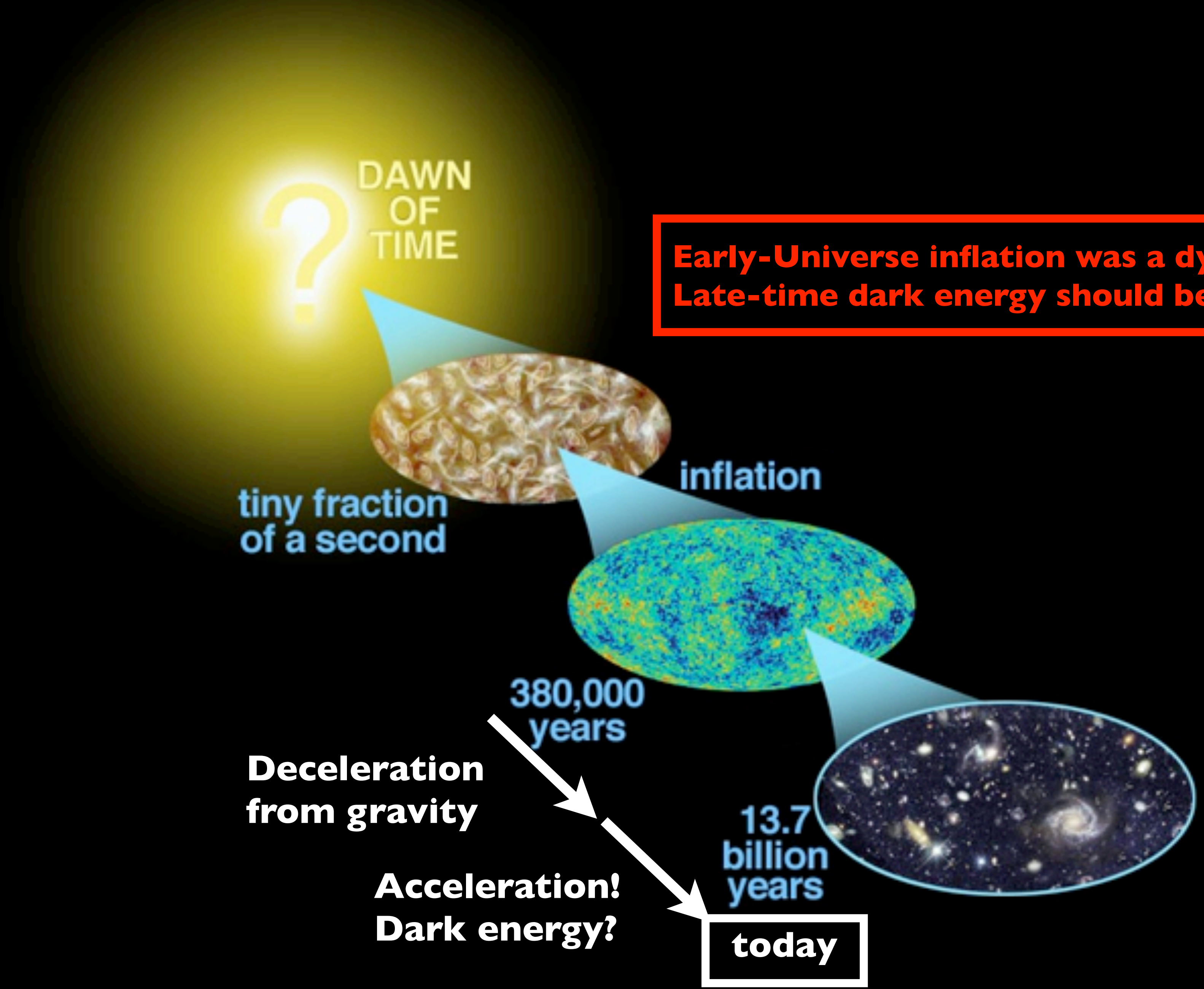
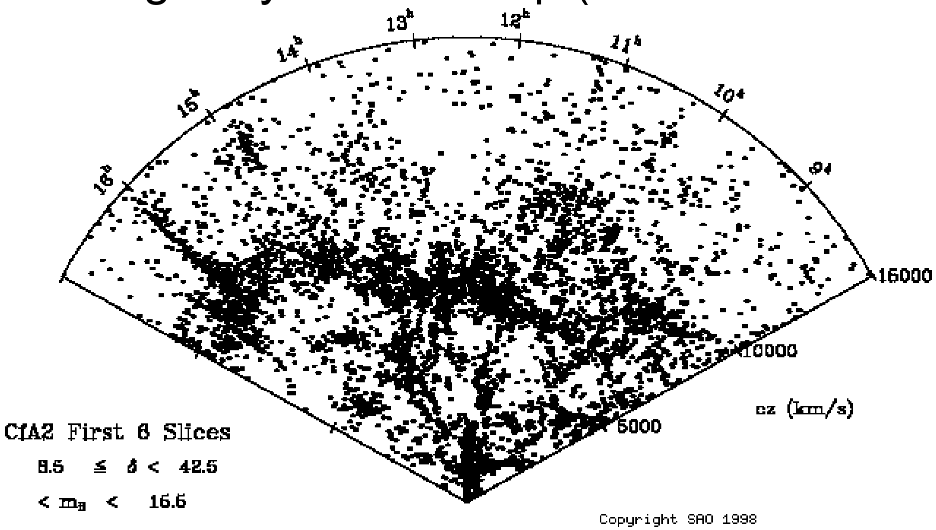
Early-Universe inflation was a dynamic field
Late-time dark energy should be as well?!



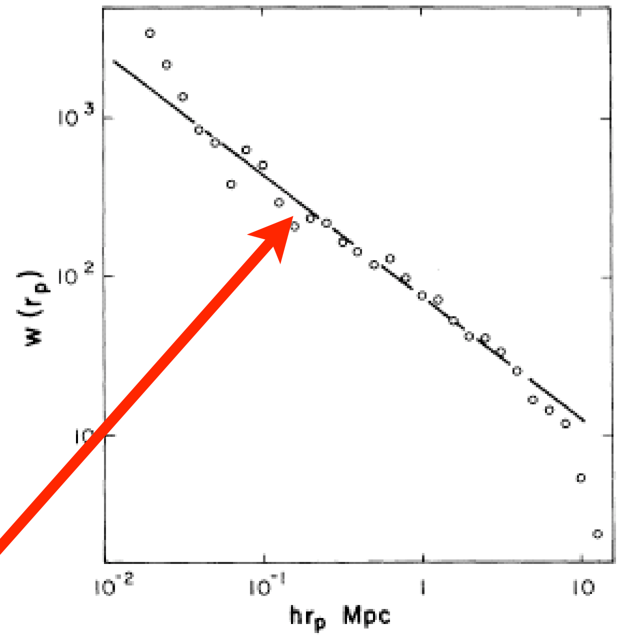
Why map the sky?

Earliest maps of the Universe were limited

CfA2 galaxy redshift map (Geller & Huchra 1989)



Correlation function

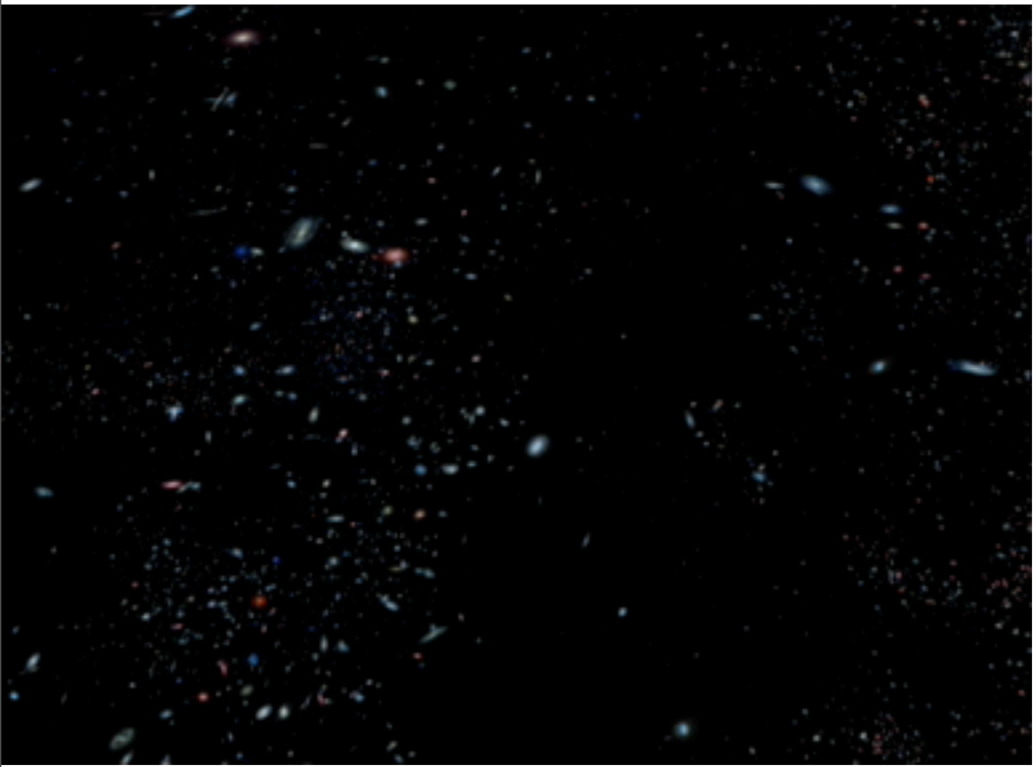


What did we learn?
Galaxy (~matter) fluctuations are ~Gaussian, scale-free
Grav. growth explains CMB fluctuations → galaxy

Why map the sky?

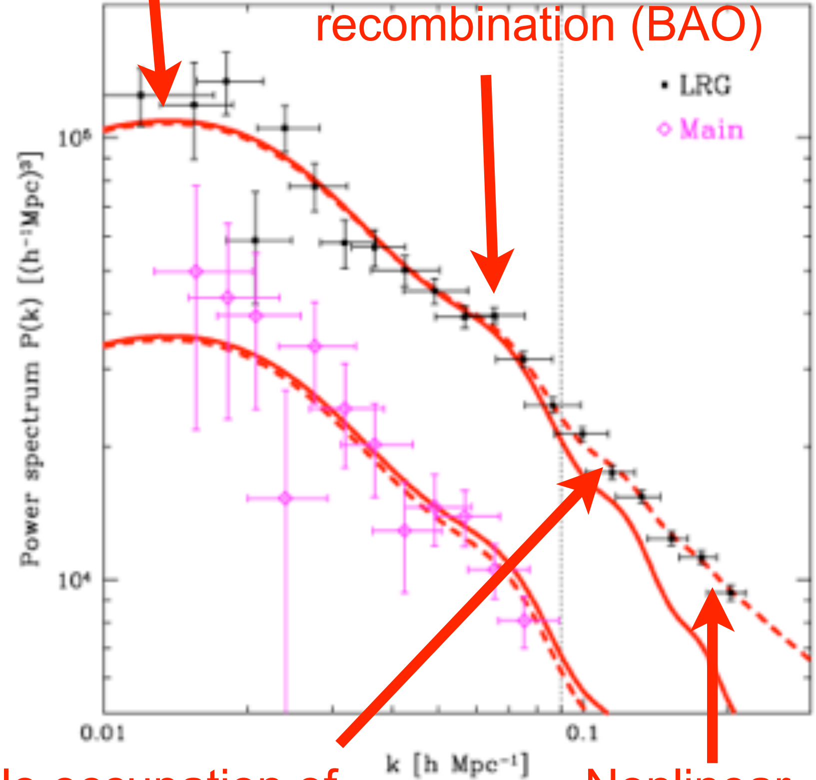
Today's maps of the Universe

SDSS galaxy redshift map



Turn-over depends upon horizon size at matter-radiation equality

Sound horizon scale at recombination (BAO)



Galaxy halo occupation of dark matter halos (HOD)

Nonlinear growth

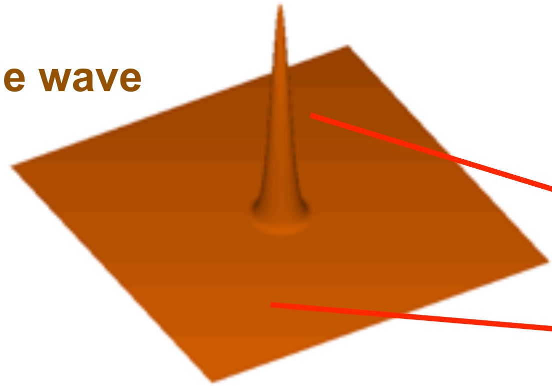
Why map the sky?

Baryon Acoustic Oscillations (BAO)

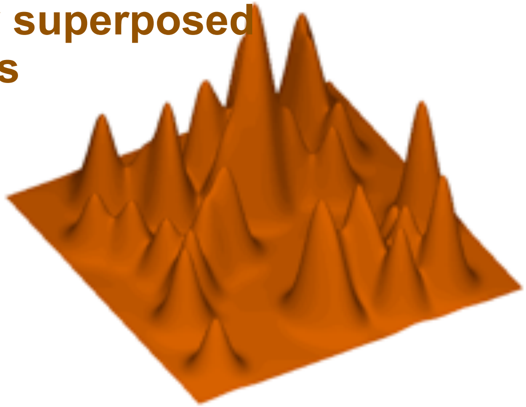
Sound waves traveled 500 million light years in the plasma of the early Universe, then abruptly stopped.

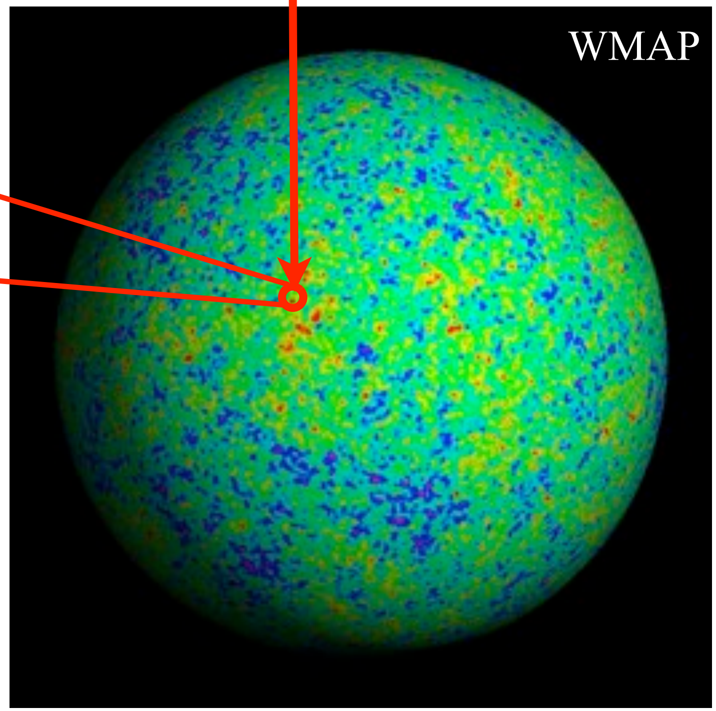
We can use this as a "***standard ruler***"

One wave



Many superposed waves





Map of Universe at 400,000 years (CMB)

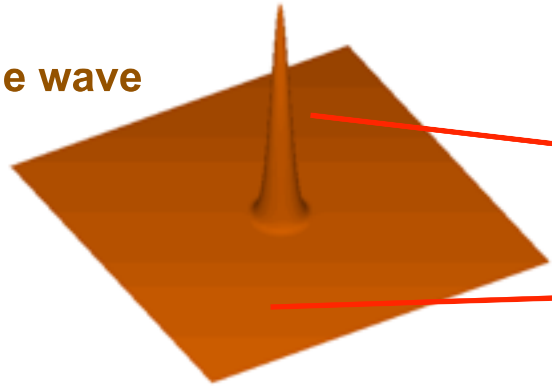
Why map the sky?

Baryon Acoustic Oscillations (BAO)

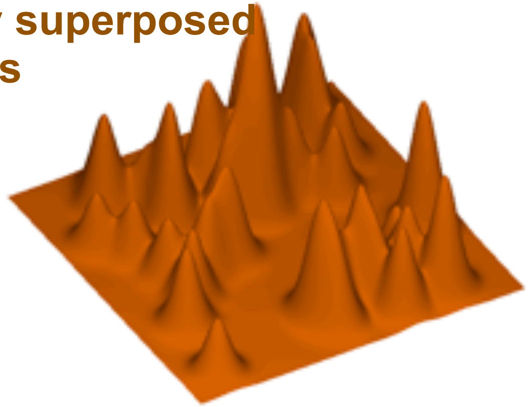
Sound waves traveled 500 million light years in the plasma of the early Universe, then abruptly stopped.

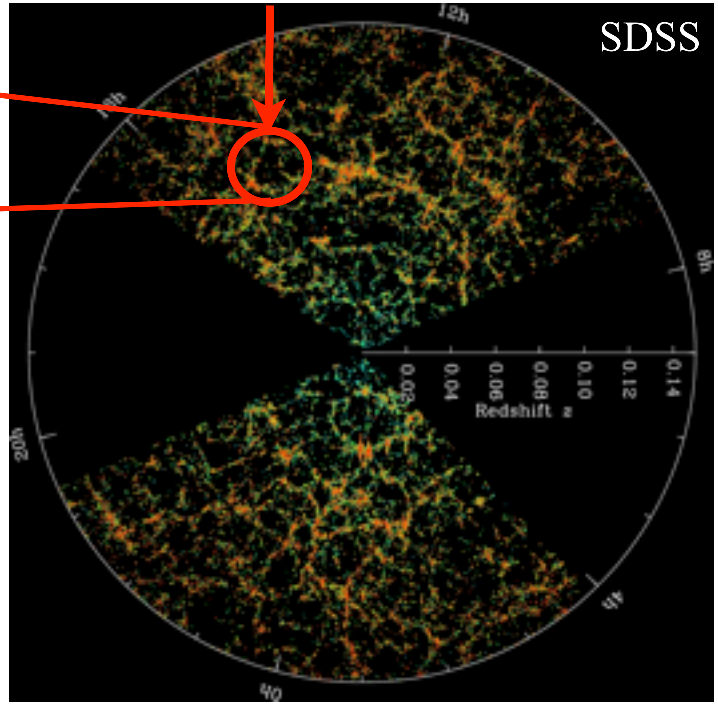
We can use this as a "***standard ruler***" (if a little inconveniently long!)

One wave



Many superposed waves





Map of galaxies today

Why map the sky?

Baryon Acoustic Oscillations (BAO)

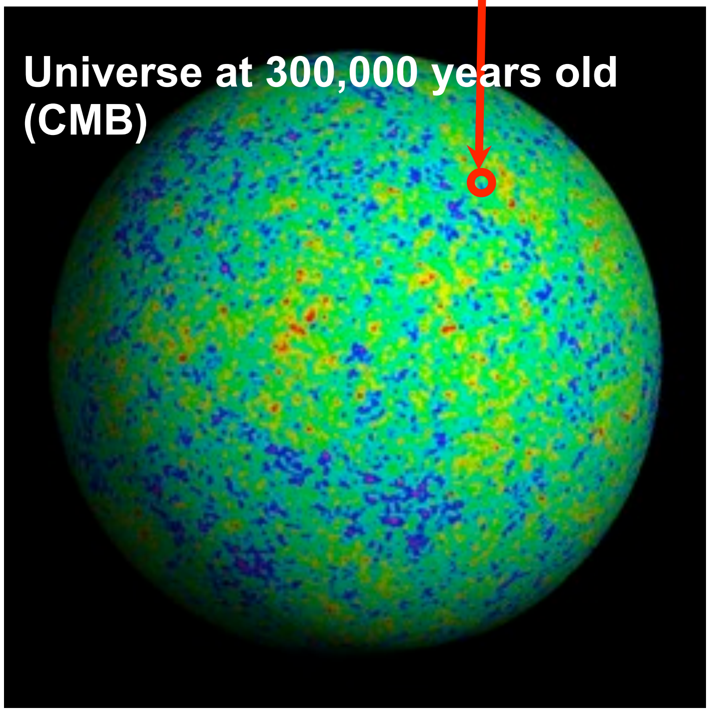
Precision dark energy probe from BAO scale

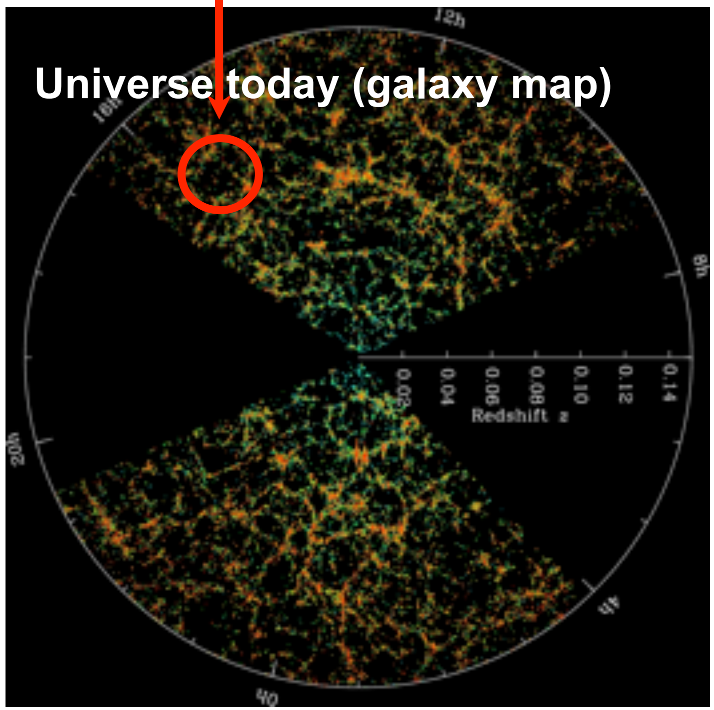
Inflation probe from non-gaussian fluctuations

- Better than Planck or JDEM

These fluctuations of 1 part in 10^5 gravitationally grow into...

...these ~unity fluctuations today





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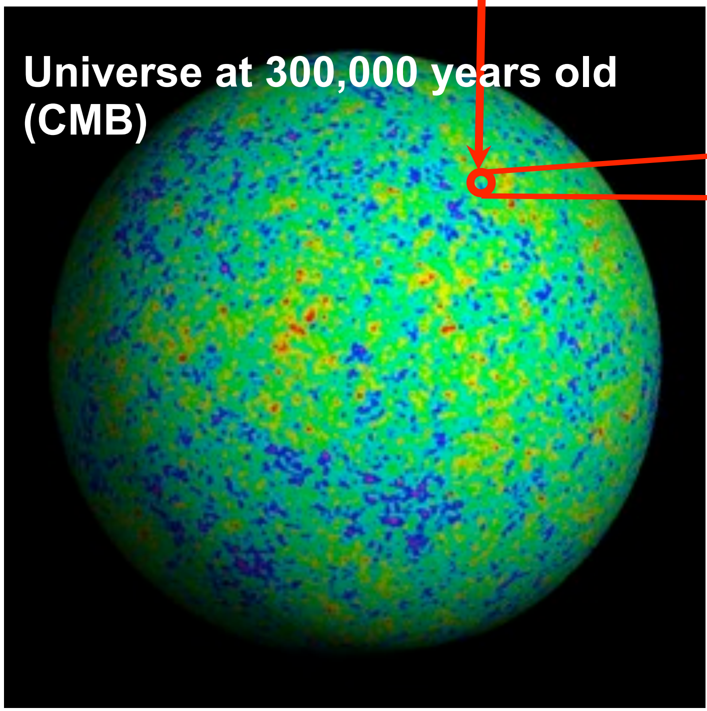
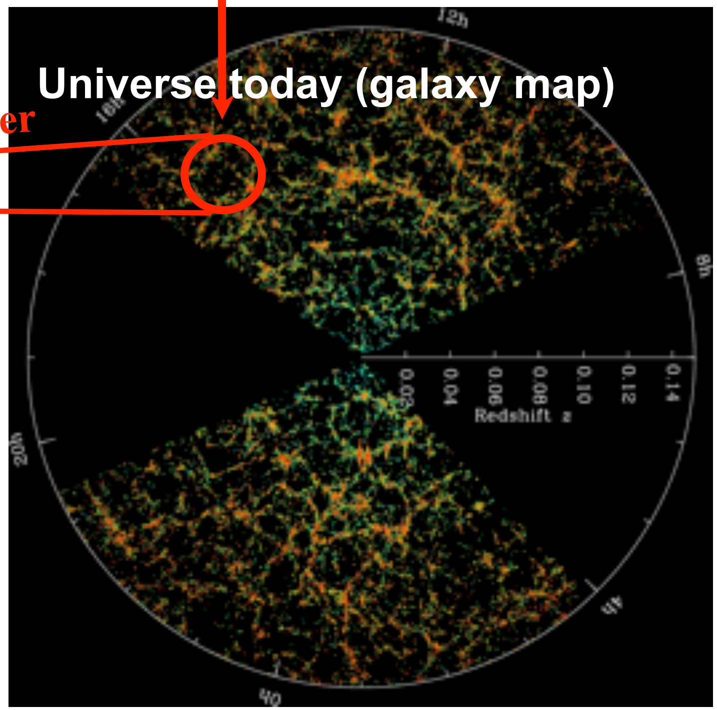
standard ruler

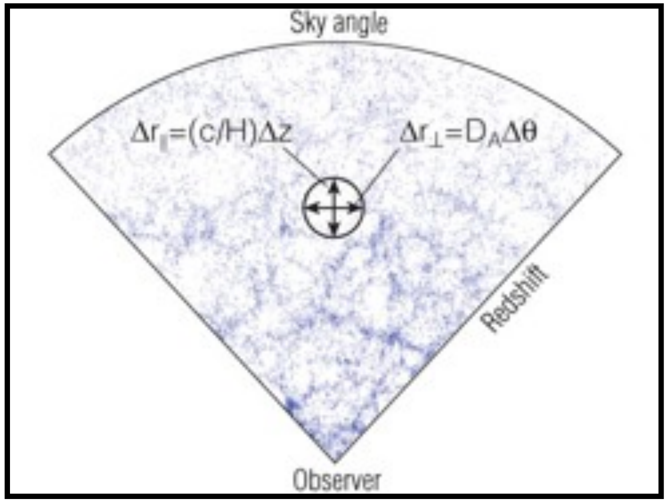




BAO and dark energy

What we like...

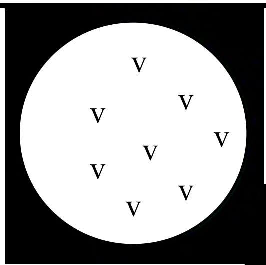
- Like supernovae, a geometrical probe of the expansion rate (and dark energy)
- The acoustic oscillation scale depends on the sound speed and the propagation time
- Anchored at recombination (z=1088) by the CMB
- **Orientation of ruler provides two different probes**
  - **Transverse rulers probes $D_A(z)$**
  - **Line of sight rulers probe $H(z)$**
- These depend on the matter-to-radiation ratio ($\Omega_m h^2$) and the baryon-to-photon ratio ($\Omega_b h^2$)
- Only need to make 3D maps (angles + redshifts)

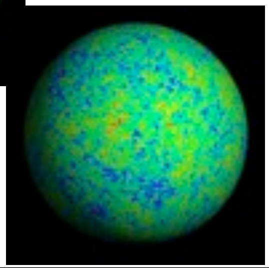


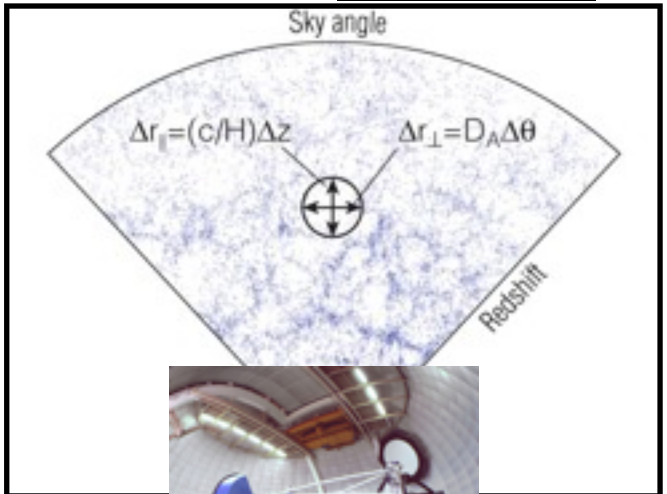
What we don't like...

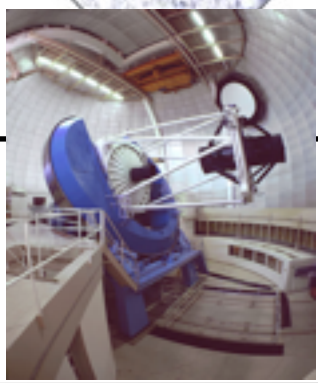
- Ruler is inconveniently long → 150 Mpc = 450 million light years
- **Statistical measure of a small signal → Requires mapping millions of objects**
- There is a cosmic variance limit... once we reach that, we're done!

BAO and dark energy









BAO: What tracer objects to use?

$z=10^{11}$ Neutrino background
(not for BAO ruler, but horizon at v decoupling)

$z=1087$ CMB: Planck will measure d_A to 0.1%

$z=20$

H gas in 21-cm emission

$z=5$

Ly-A emitter galaxies
QSO absorption lines

All existing BAO measurements

$z=2$

Galaxies,
galaxy clusters,
SNe

Definitely the hard way, but it's been suggested!
(Angulo et al 2006)
(Zhan et al 2008)

$z=0$

BAO and dark energy

Important note: We need only sparsely sample these tracers

Requirement: Sample linear modes at 100 h^{-1}Mpc

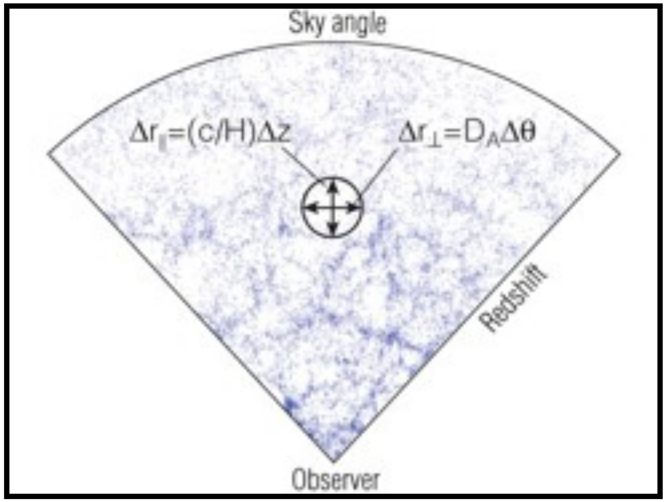
Shot noise ~ (1 + 1/nP)

P = power at 100 Mpc

n = sampling density

Shot noise small if nP>3 ⇒ n > 1 per $(10\ h^{-1}\mathrm{Mpc})^3$n

If tracers are ***biased*** relative to dark matter, we need even fewer (because P>1)



z=20

H gas in 21-cm emission

z=5

Ly-A emitter galaxies

QSO absorption lines

z=2

Galaxies,

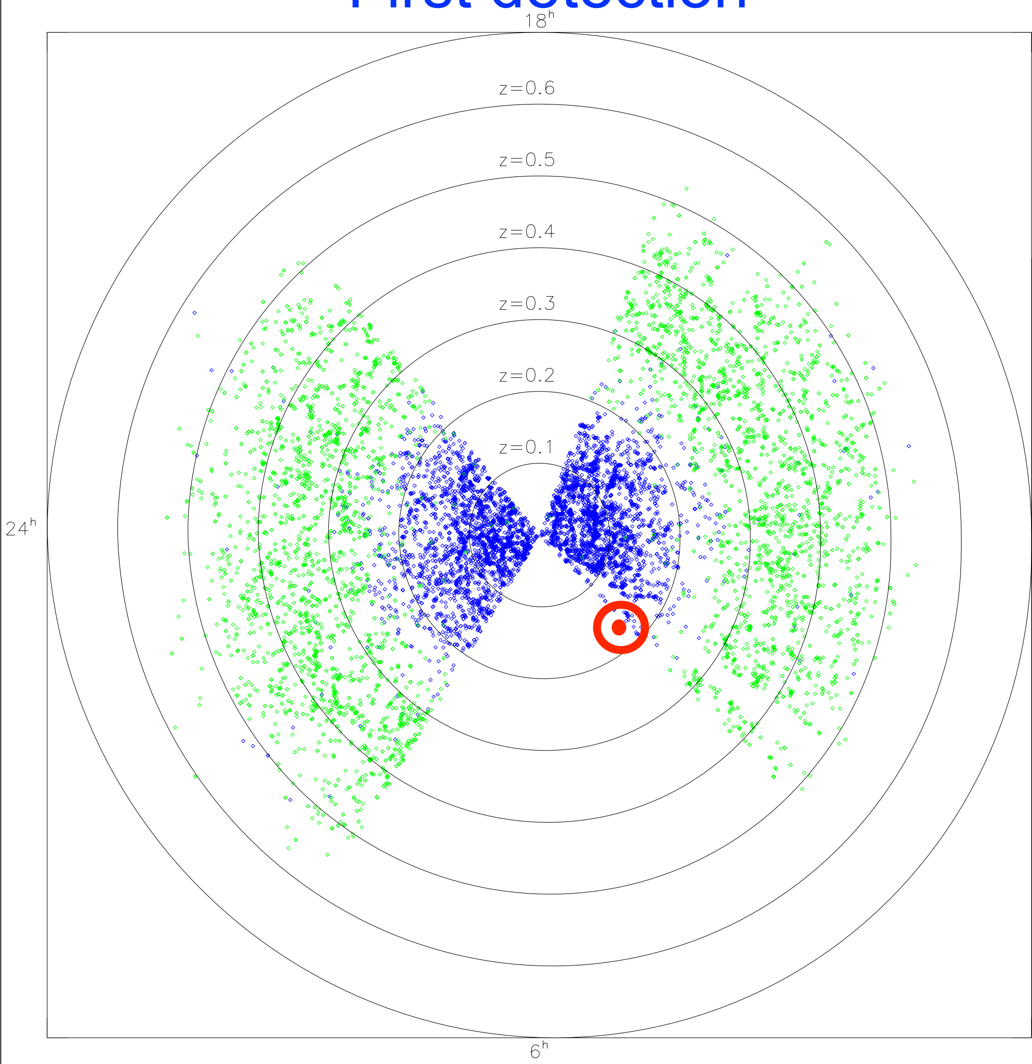
galaxy clusters,

SNe

z=0

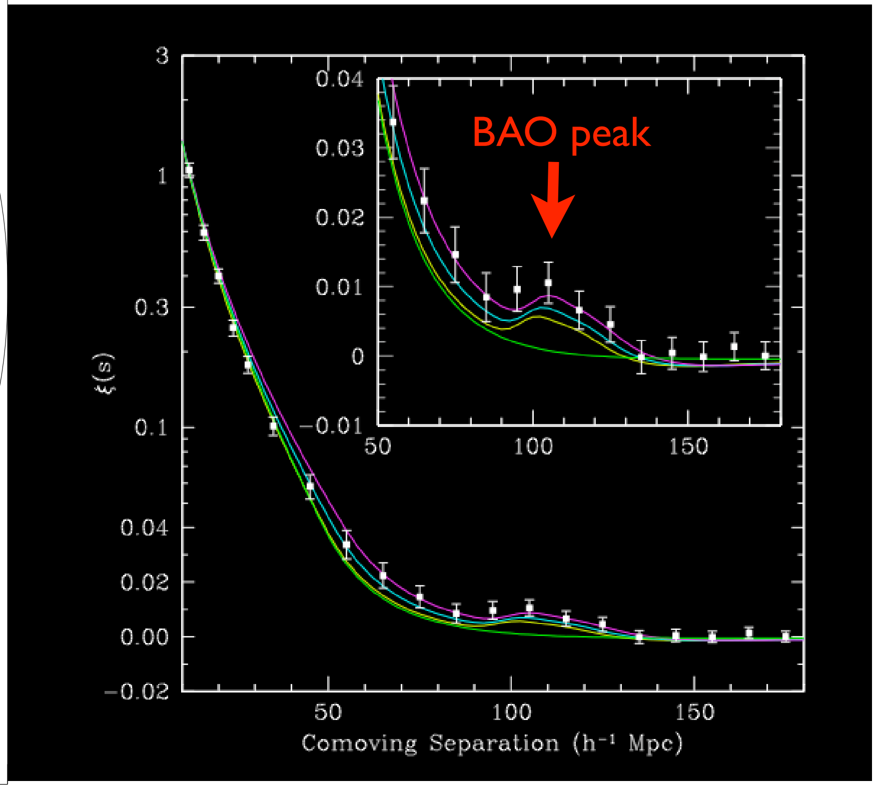
BAO from 3-D maps: SDSS

First detection



SDSS luminous red galaxies (LRGs)

- Sparse sampled at 10^{-4} galaxies/Mpc^3
- 47,000 galaxies over 4000 deg^2 by 2004
- 80,000 galaxies over 8000 deg^2 by July 200



Eisenstein et al 2005

BOSS == Baryon Oscillation Spectroscopic Survey
Next-Generation BAO Experiment

A variety of facilities considered for next-gen BAO experiment:
Lick 3-m, Keck 10-m, MMT 6.5-m, ...

SDSS telescope secured for next-gen BAO experiment:
July 2006: Telescope proposals for SDSS-III
Nov 2006: BOSS proposal selected for dark+grey time 2009-2014
Feb 2007: DOE R&D proposal
Sep 2007: Commitment from Alfred P. Sloan Foundation
June 2008: Commitment from NSF
Jan 2009: Commitment from DOE

BOSS == Baryon Oscillation Spectroscopic Survey
Next-Generation BAO Experiment

SDSS-III Collaboration:

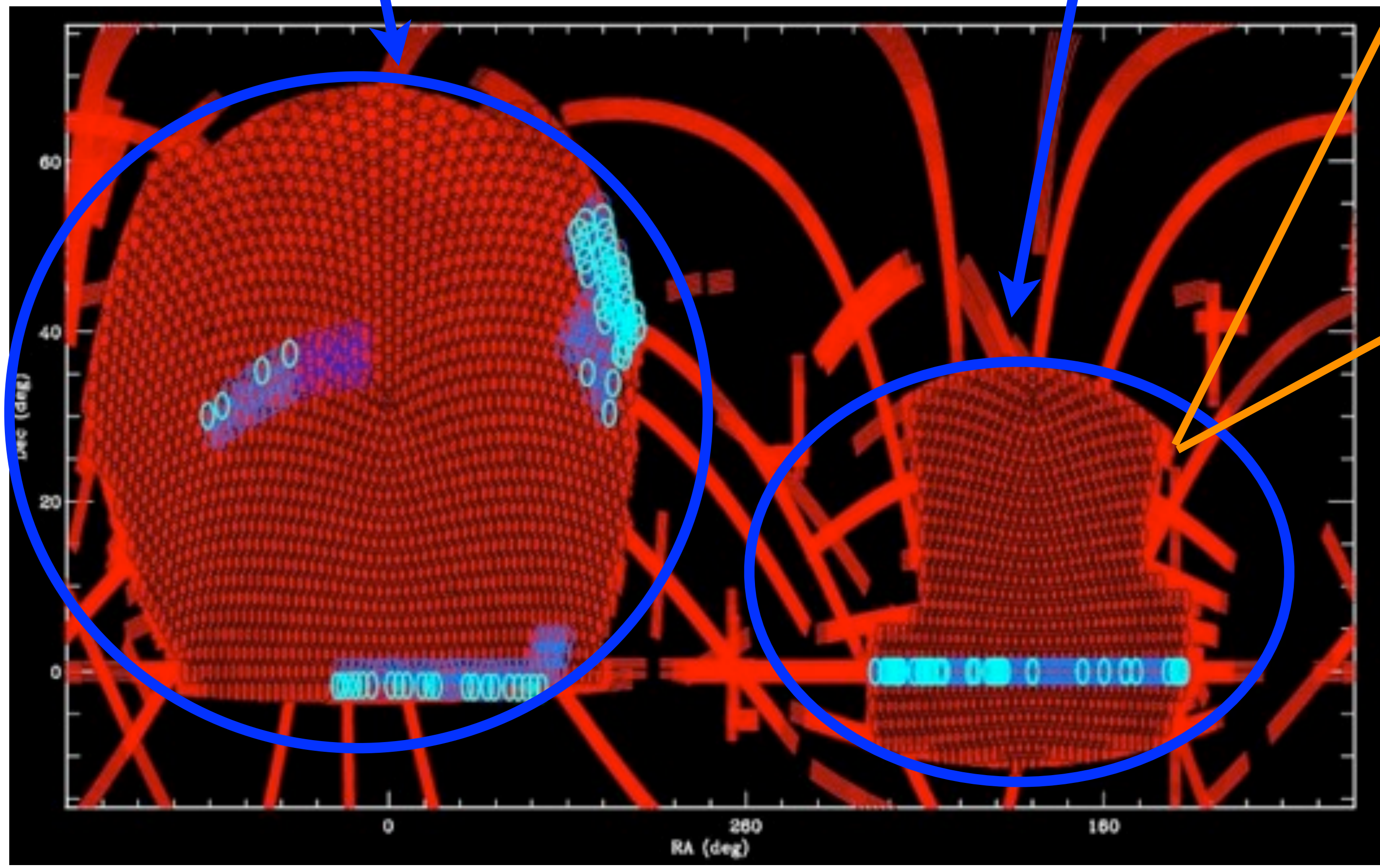
- University of Arizona
- Brazilian Participation Group (ON, UFRGS, UFRN, UFRJ)
- Brookhaven National Lab
- Cambridge University
- Case Western University (A)
- University of Florida
- French Participation Group
- German Participation Group (AIP, MPE, MPIA, ZAH)
- Johns Hopkins University
- Korean Institute for Advanced Study (A)
- Lawrence Berkeley National Laboratory
- Max Planck Astrophysics (MPA)
- New Mexico State University
- New York University
- Ohio State University
- University of Pittsburgh (A)
- University of Portsmouth (A)
- Princeton University
- University of California, Santa Cruz (A)
- University of Utah
- University of Washington
- Vanderbilt University
- Univ. of Virginia
- Yale Univ.

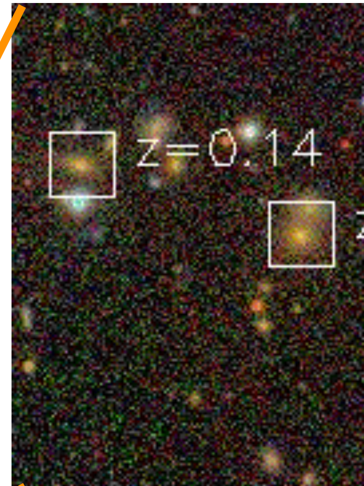
BOSS
Imaging survey for targets

All targets selected from SDSS
Requires 10,000 deg^2 footprint

SDSS & SDSS-II imaging
7600 deg^2

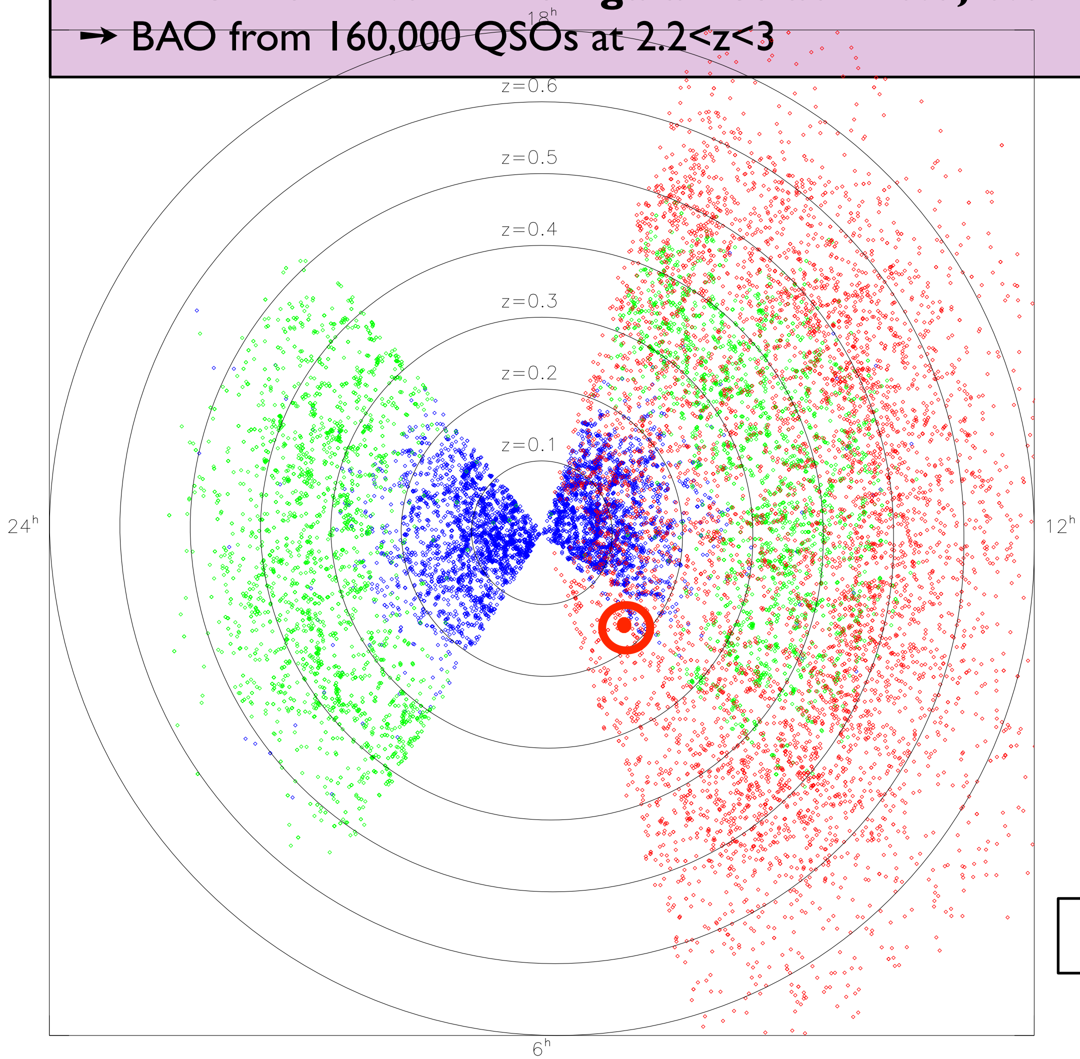
BOSS imaging
...add 3100 deg^2 in 2008-2009





BOSS == Baryon Oscillation Spectroscopic Survey

Two simultaneous spectroscopic surveys from 2009-2014
→ **BAO from 1.3 million galaxies at z=0.3, 0.6**
→ BAO from 160,000 QSOs at 2.2<z<3



SDSS main galaxy survey
~1 million galaxies
Too little volume for BAO

SDSS luminous red galaxies (LRGs)
80,000 galaxies
Sparse sampled at 10^{-4} galaxies/$(h^{-1}Mpc)^3$

BOSS red galaxies
10,000 deg^2
5x sample density (shot noise)
2x volume

Turn this photo-z sample → spectro-z

BOSS == Baryon Oscillation Spectroscopic Survey

Two simultaneous spectroscopic surveys from 2009-2014
→ BAO from 1.3 million galaxies at z=0.3, 0.6
→ **BAO from 160,000 QSOs at 2.2<z<3**

$$P_{\mathrm{raw}}(\mathbf{k}) = \left[P_F(\mathbf{k}) + n^{-1} P_F^{1\mathrm{D}}(k_{\|})\right] W^2\left(k_{\|} R\right) + P_N^{\mathrm{eff}}$$

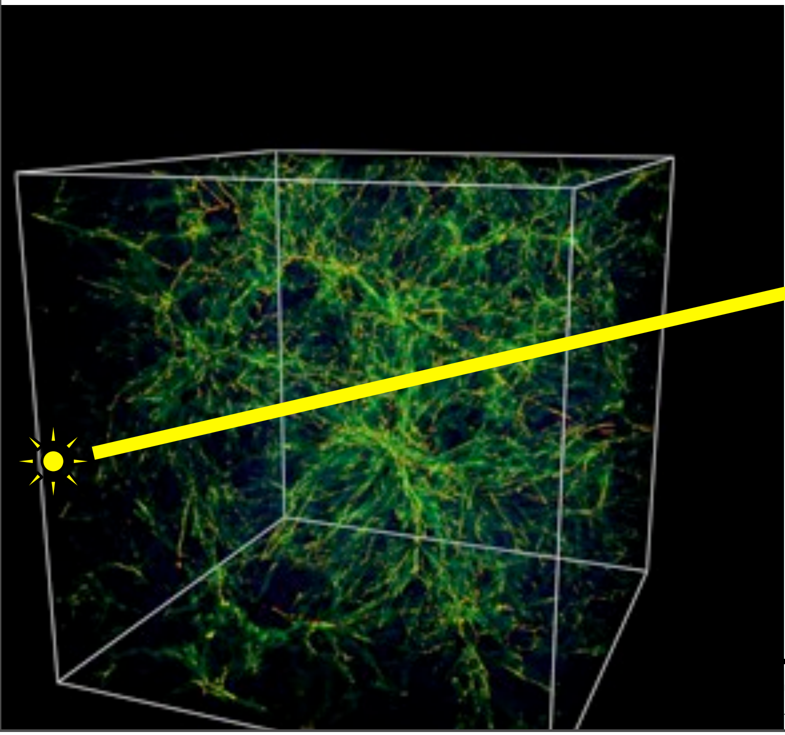
Ideal 3D power (perfectly sampled)

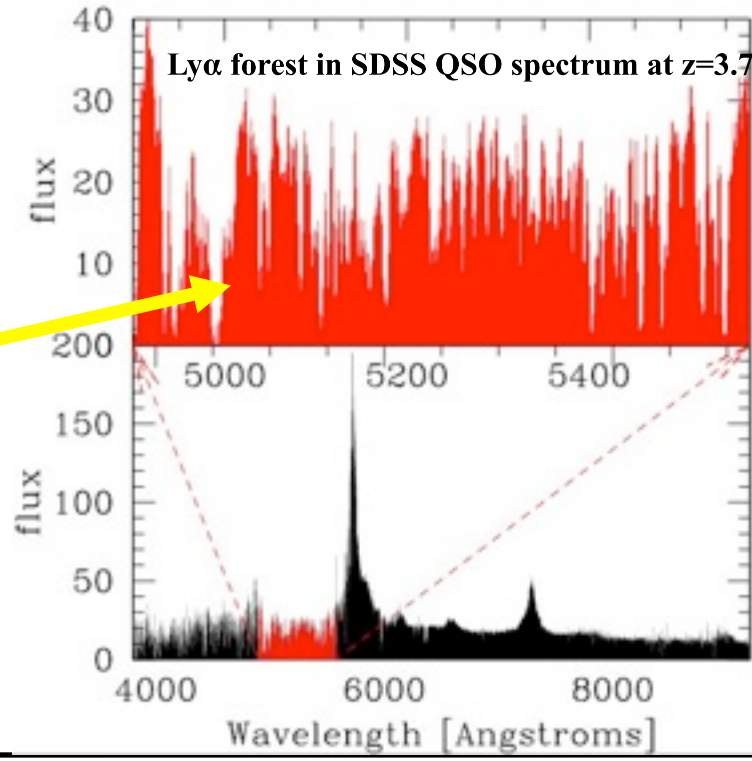
Sampling noise
n=surface density of lines of sight
(analogous to galaxy shot noise)

Resolution

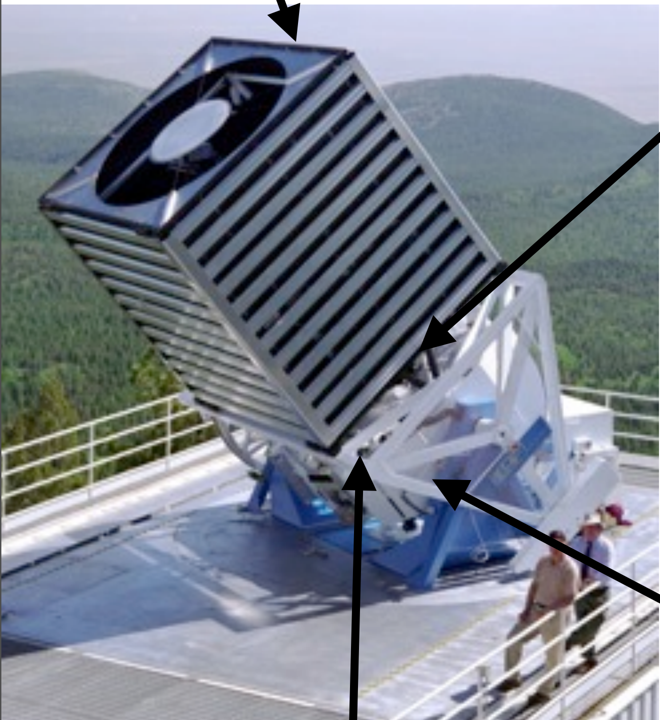
Detector noise

Simulation of the IGM (R. Cen)
Neutral H in 25 h^{-1}Mpc box



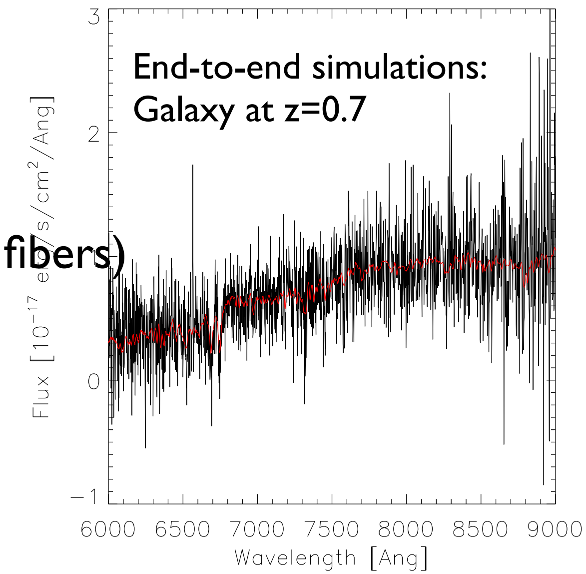


BOSS status

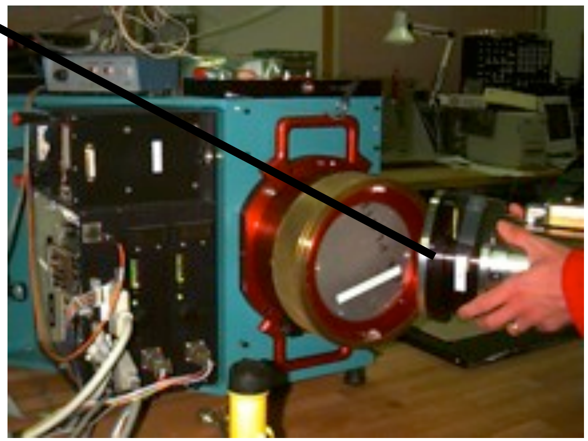


Large field-of-view -- DONE!

640 → 1000 fibers
(more objects, less sky in small fibers)



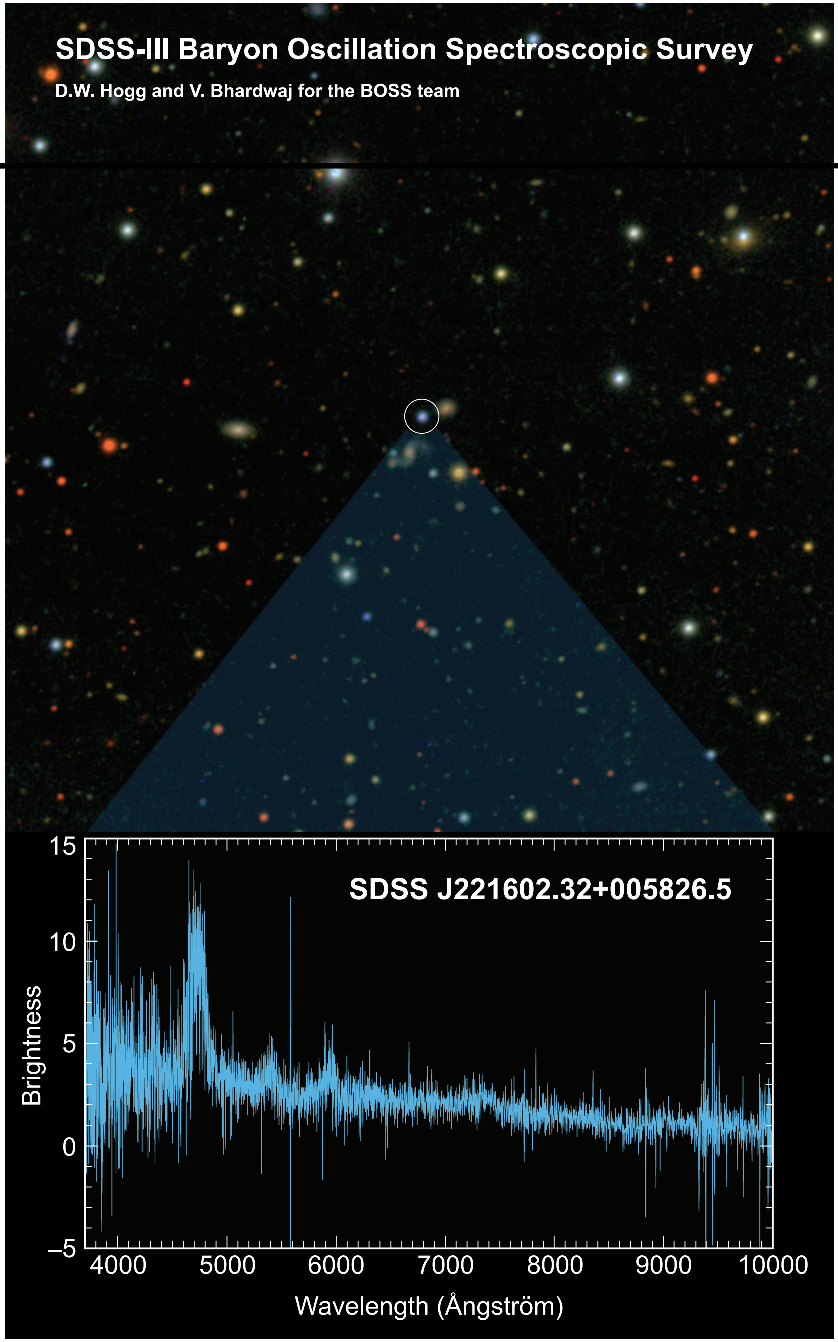
Ruled → VPH gratings



LBL/SNAP red CCDs for higher-z galaxies

e2v blue CCDs for Lyα at z=2.2→3

BOSS First Light
14-15 Sep 2009

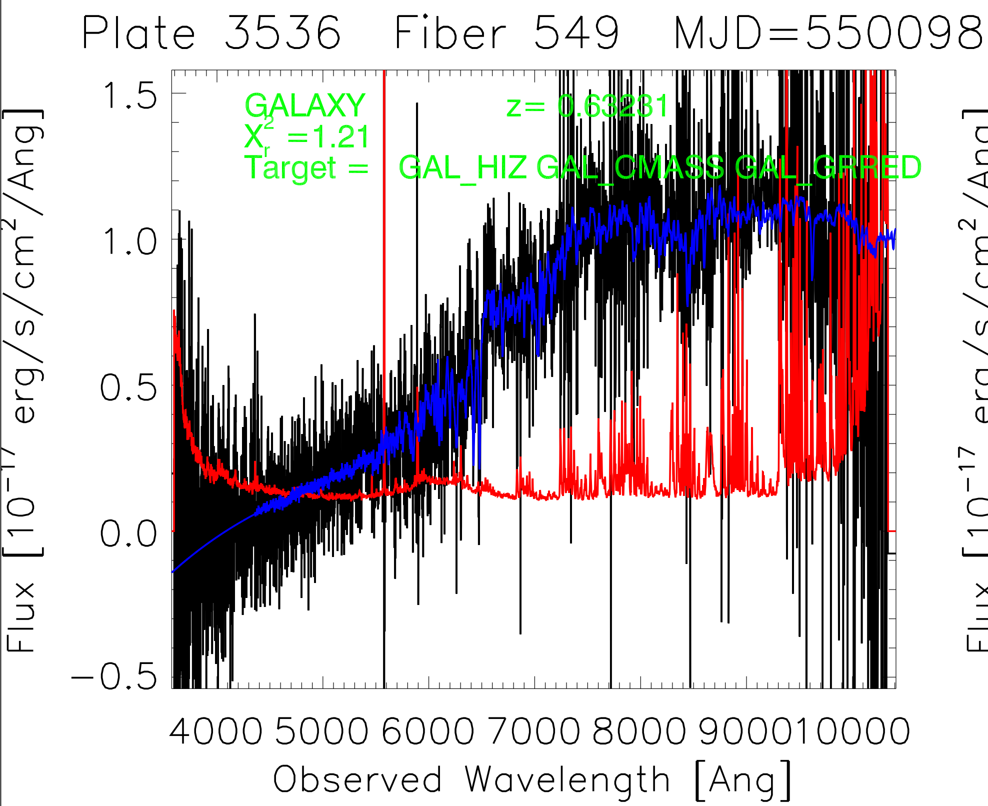


BOSS First Light

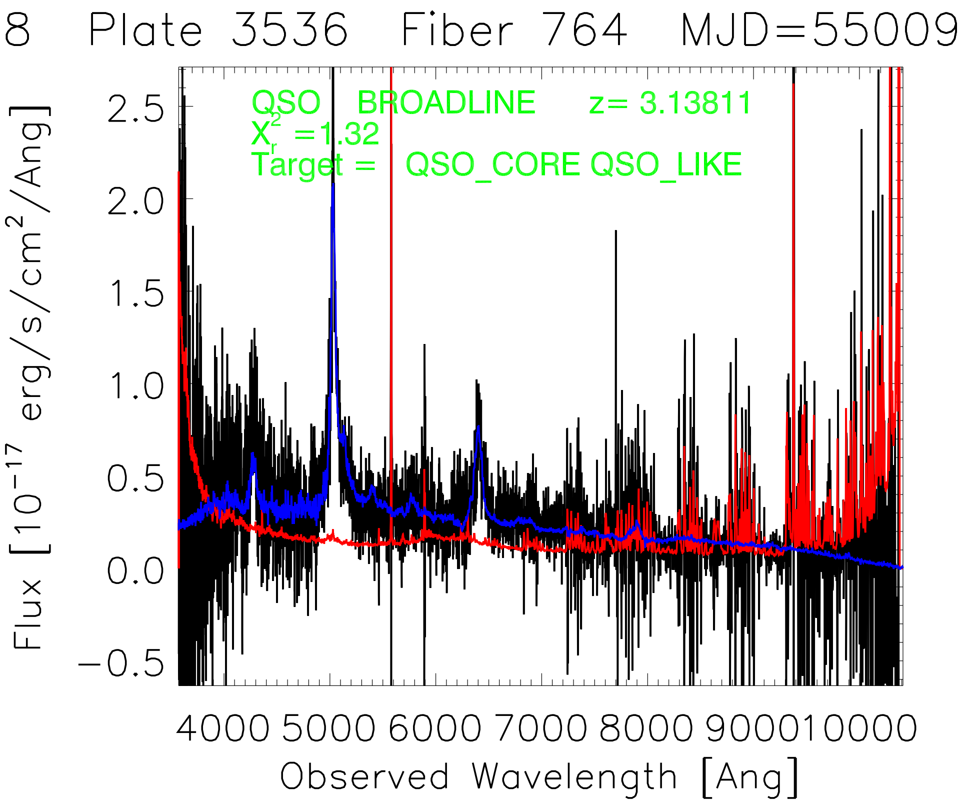
14-15 Sep 2009

We're the "noisy data" survey

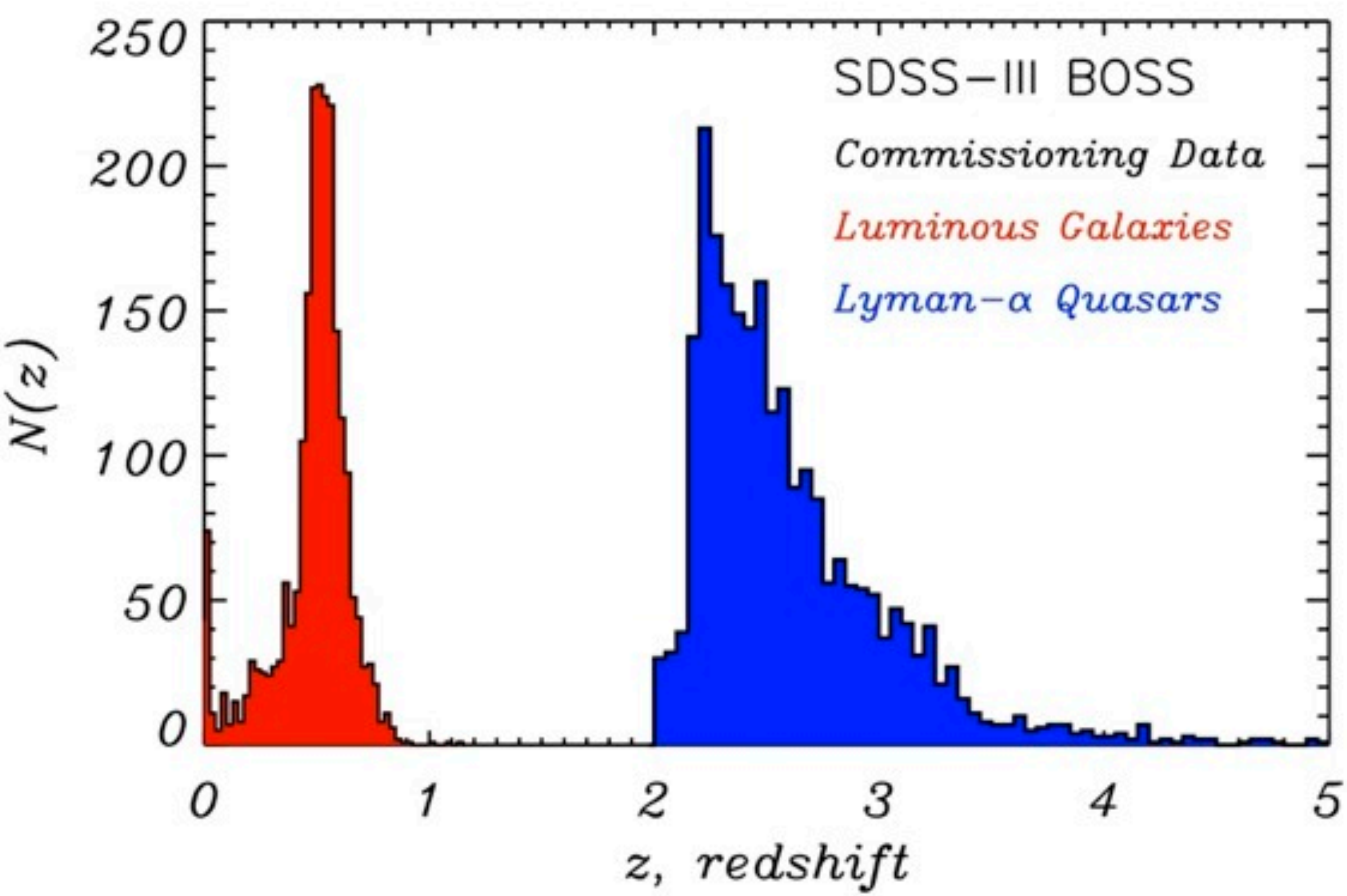
Galaxy *i-band*=20, z=0.6



QSO *g-band*=22, z=3.1



BOSS commissioning data



BOSS: Baryon Oscillation Spectroscopic Survey

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→ **BAO from 1.5 million galaxies at z=0.3, 0.6**
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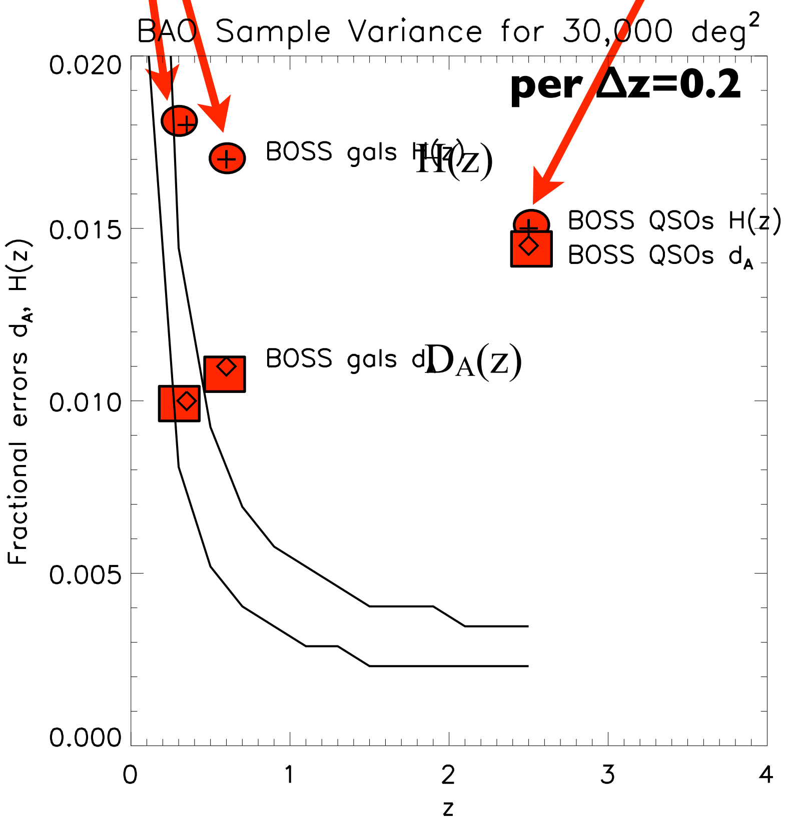
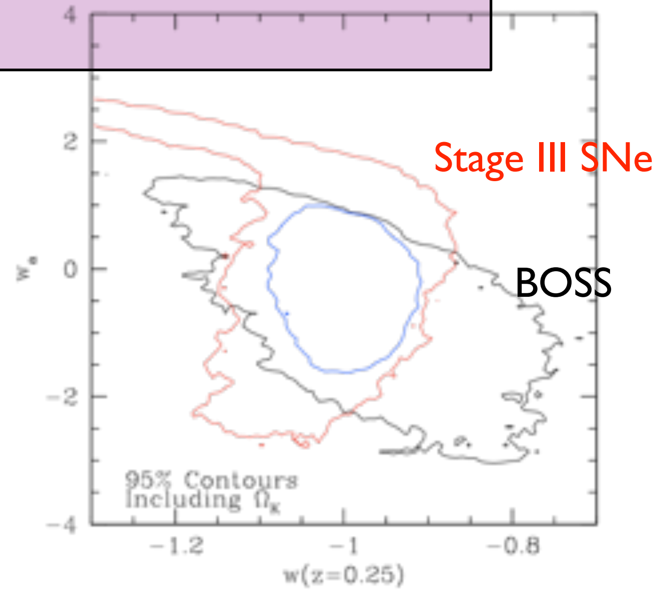
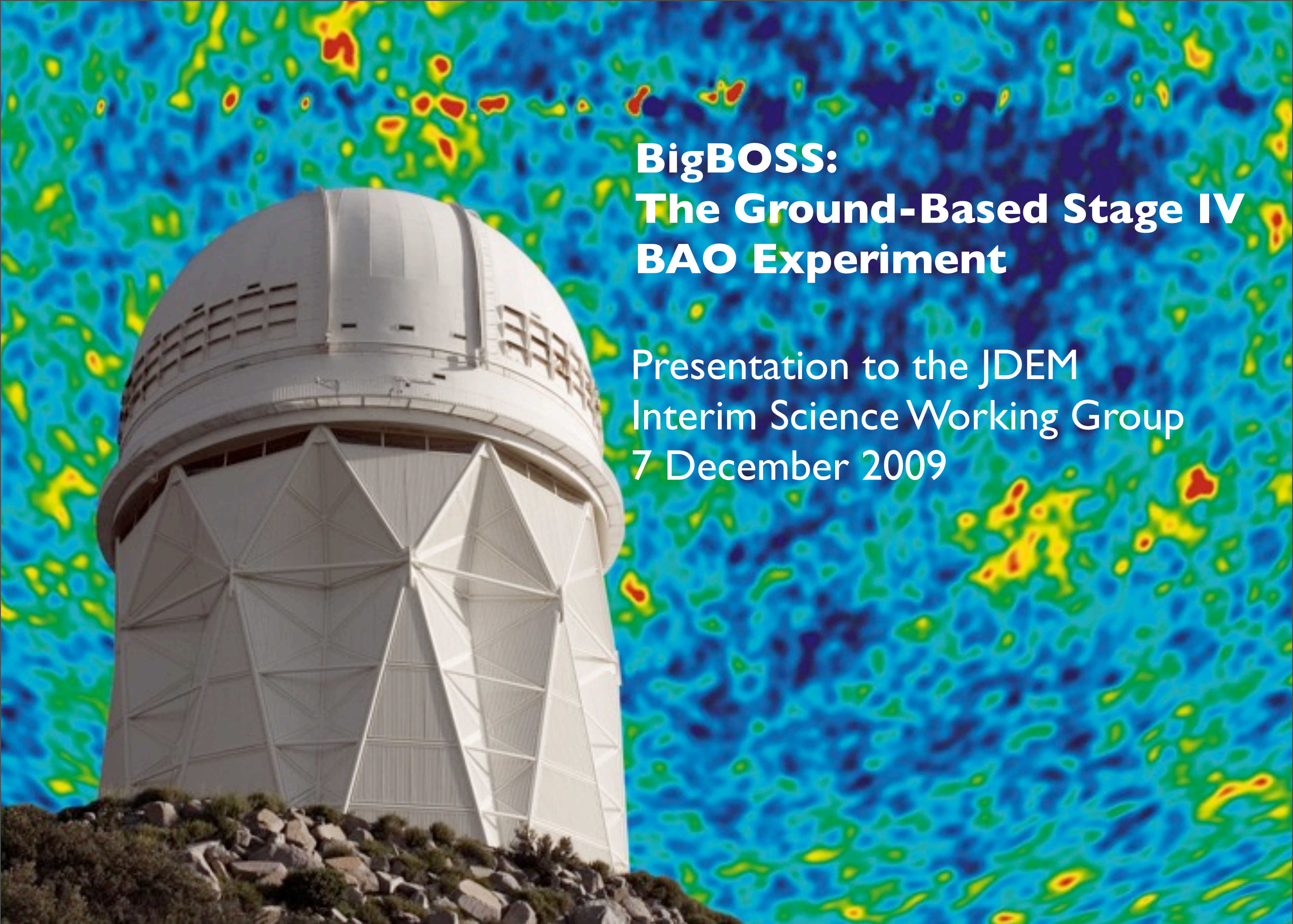




- ➤ BOSS will be near cosmic-variance limit for z<0.7
- ➤ Could improve by √2 by repeating in Southern sky
- ➤ An equivalent photo-z BAO survey would require 50,000 deg^2



BigBOSS: The Ground-Based Stage IV BAO Experiment

Presentation to the JDEM
Interim Science Working Group
7 December 2009

I. BigBOSS science

II. Pilot data: DEEP2

II. Instrument

III. Imaging + Targets

IV. Status

I. BigBOSS science

II. Pilot data: DEEP2

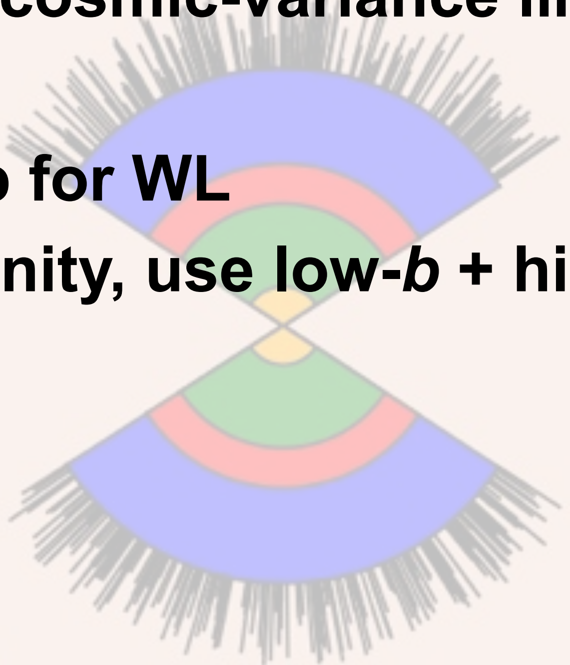
II. Instrument

III. Imaging + Targets

IV. Status

BigBOSS Science Goals

- ➪ BAO $z=0 \rightarrow 3.5$ near cosmic-variance limit
- ➪ RSD $z=0 \rightarrow 3.5$
- ➪ Galaxy density map for WL
- ➪ Detect non-gaussianity, use low-*b* + high-*b* sources



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- ➯ BAO z=0→3.5 near cosmic-variance limit
- ➯ RSD z=0→3.5
- ➯ Galaxy density map for WL
- ➯ Detect non-gaussianity, use low-*b* + high-*b* sources

BigBOSS Design Philosophy

- ➯ Optimize for z's only
- ➯ Simple design ⇔ high throughput
- ➯ "Full-sky"

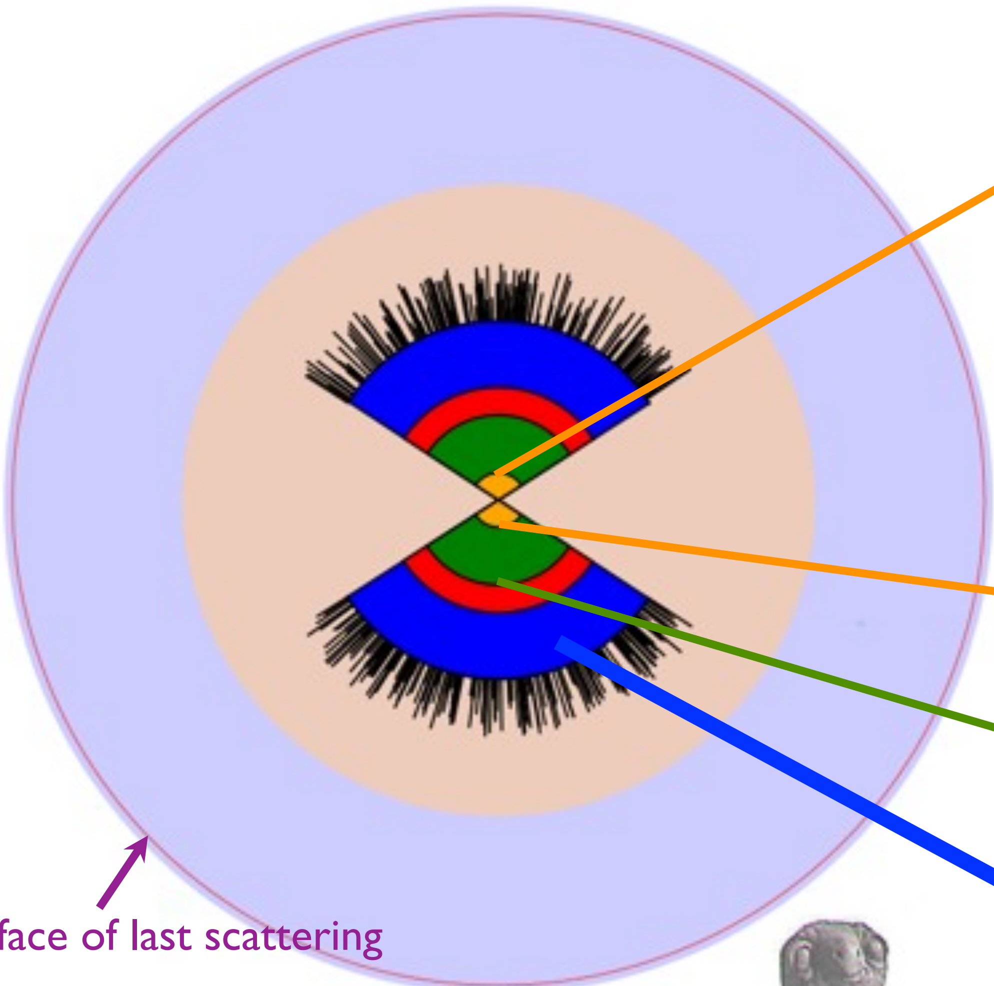
The Ground-Based Stage IV BAO Experiment

BigBOSS

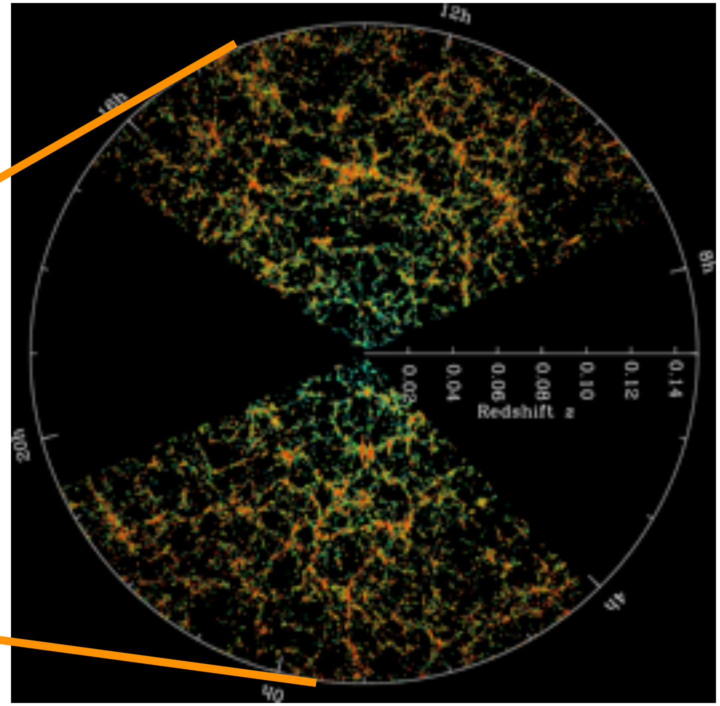
Science Goals: BAO from 50 million redshifts

Sensitivity to new physics scales as volume surveys -- # of modes

Our observable Universe



Volume mapped by SDSS + SDSS-II



Volume to be mapped by SDSS-III/BOSS (ca. 2015)

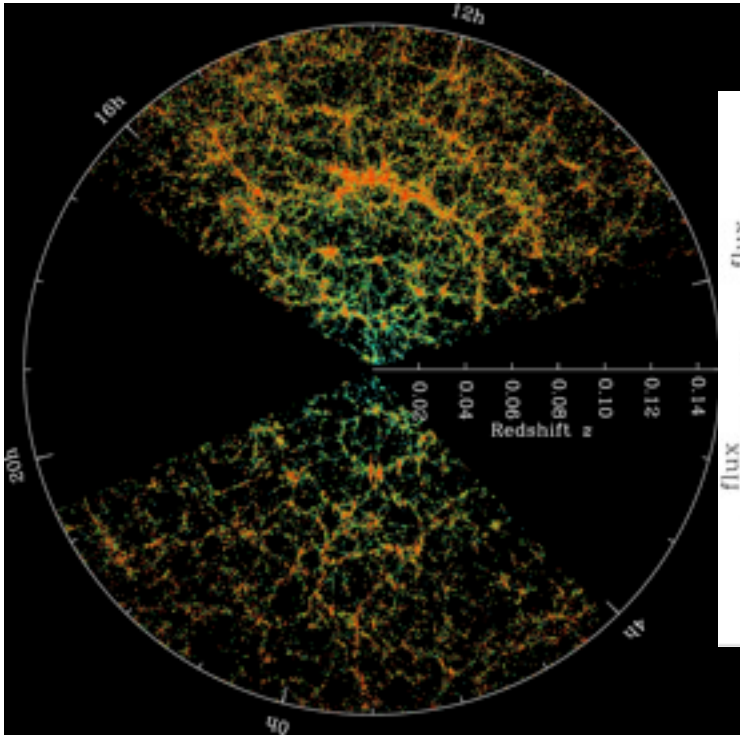
Surface of last scattering

BigBOSS @NOAO

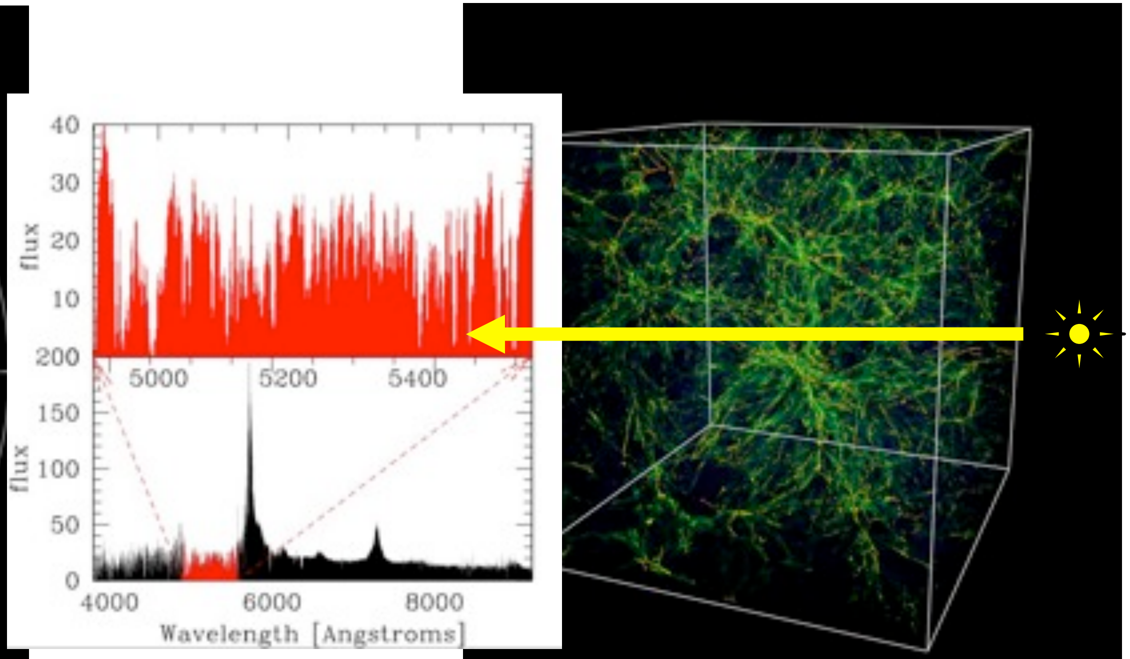
Science Goals:
BAO from 50 million redshifts

Simultaneous spectroscopic surveys from 2015-2025
→ BAO from 50 million galaxies at $0 < z < 2$
→ BAO from 1+ million QSOs at $2<z<3.5$

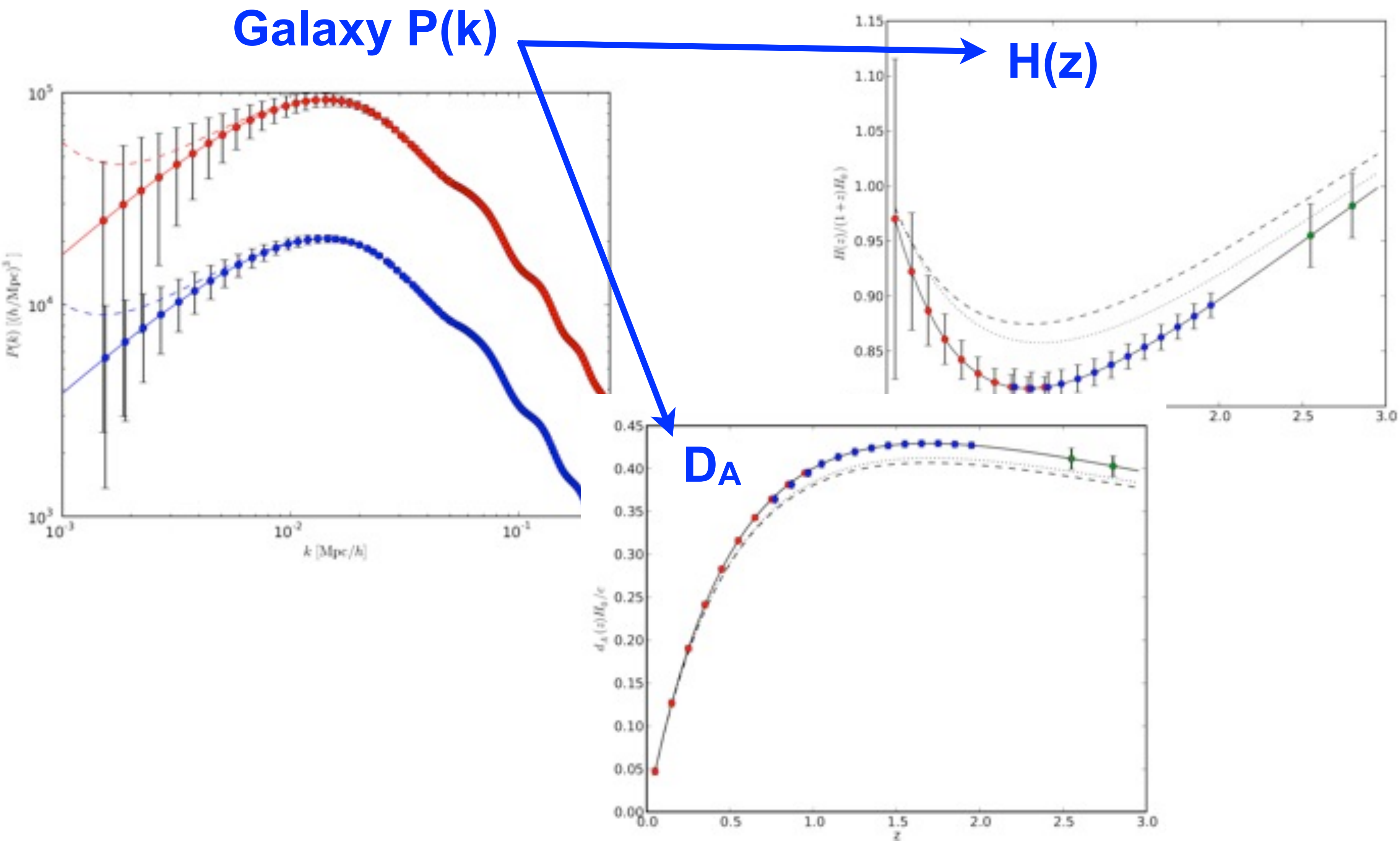
Galaxy map



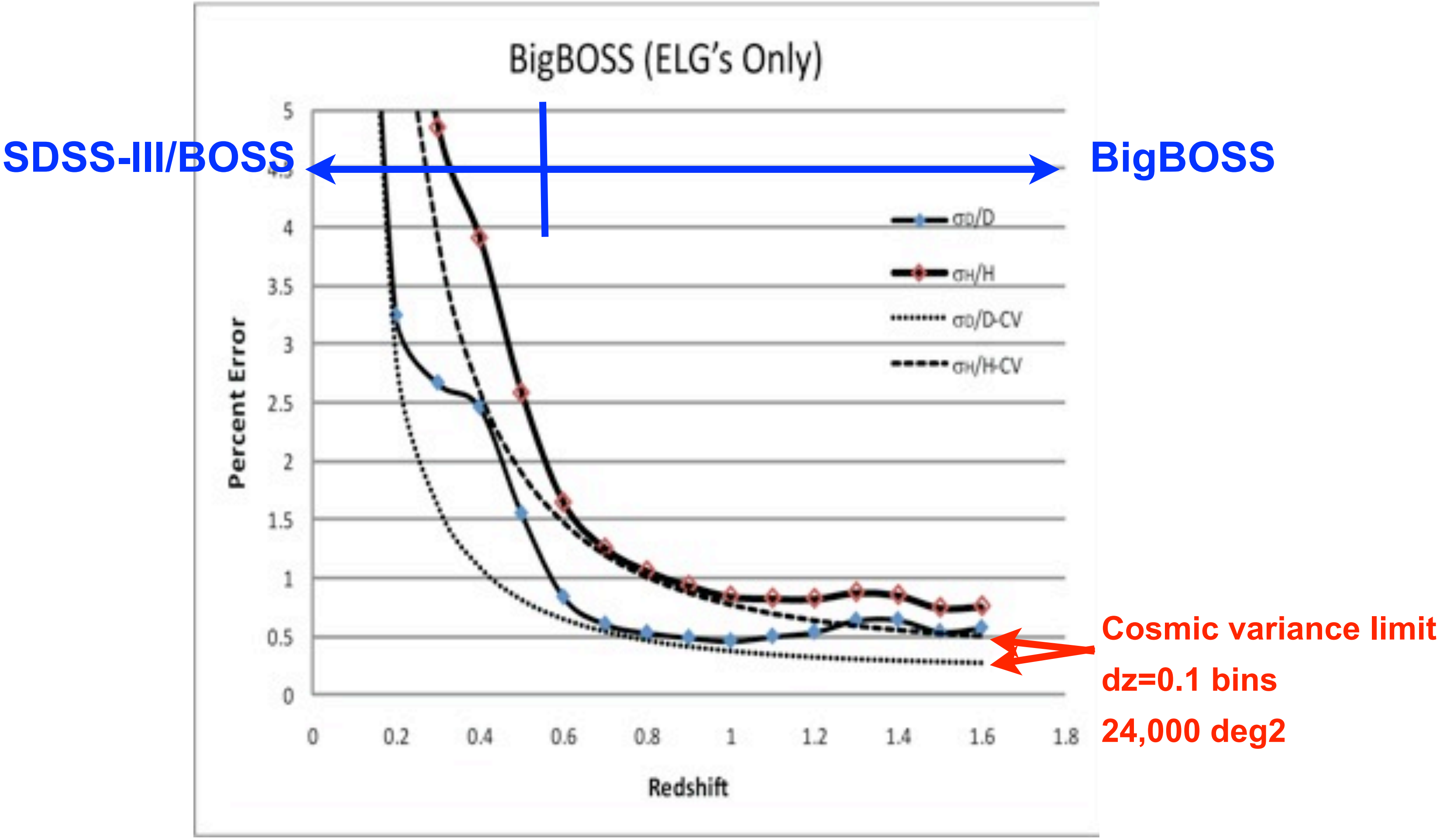
QSOs as back-light to hydrogen gas



Science Goals: BAO from 50 million redshifts



Science Goals:
BAO from 50 million redshifts

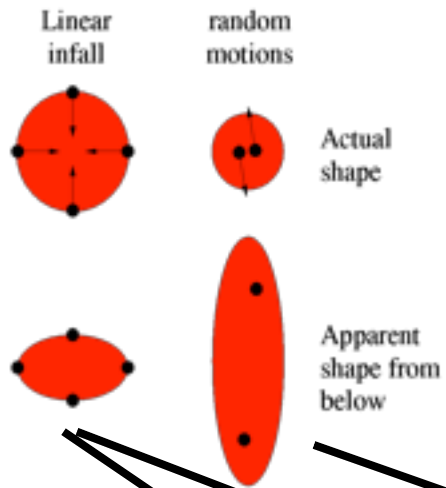


Courtesy: R. Cahn

The Ground-Based Stage IV BAO Experiment
BigBOSS

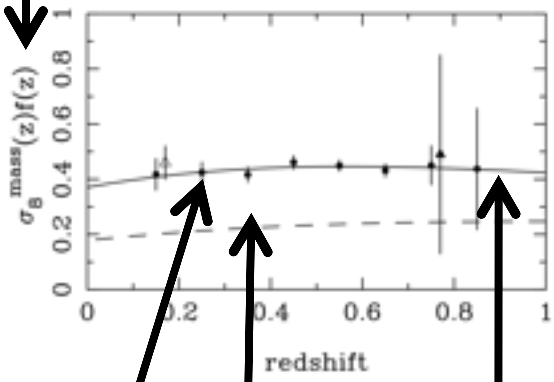
Redshift-space distortions: Gravitational probe of dark energy

Predictions based on simulations fitting formulae (Guzzo et al '08)
Current data from 2dF, SDSS (Hawkins et al '02, Percival et al '04)



$$P^s_{gg}(\mathbf{k}) = \left[P_{gg}(\mathbf{k}) + \frac{2\mu^2}{aH}P_{g\theta_g}(\mathbf{k}) + \frac{\mu^4}{(aH)^2}P_{\theta_g\theta_g}(\mathbf{k})\right] F\left(\frac{k^2\mu^2\sigma_v^2}{H^2(z)}\right)$$

Redshift-space distortions measure amplitude of velocity power spectrum



simulated BOSS data

ΛCDM model

DGP model with same expansion history as CDM

Courtesy Will Percival

BigBOSS: Inflation probe from Non-gaussianity

BigBOSS inflation constraints beat CMB!

Lyman Alpha Forest: what can it do? —Non-gaussianities in Early Universe

BERKELEY LAB

parameterize how much non-linear corrections are there to the potential

$$\Phi = \phi + f_{NL}\phi^2$$

Primordial potential (assumed to be gaussian random field)

Non-Gaussianity from Inflation

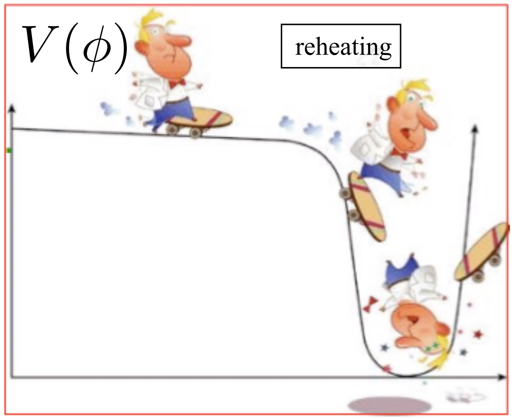
f_{NL} ~ 0.05 canonical inflation (single field, couple of derivatives) (Maldacena 2003, Acquaviva etal 2003)

f_{NL} ~ 0.1--100 higher order derivatives

- DBI inflation (Alishahiha, Silverstein and Tong 2004)
- UV cutoff (Craminelli and Cosmol, 2003)

f_{NL} >10 curvaton models (Lyth, Ungarelli and Wands, 2003)

f_{NL} ~100 ghost inflation (Arkani-Hamed et al., Cosmol, 2004)

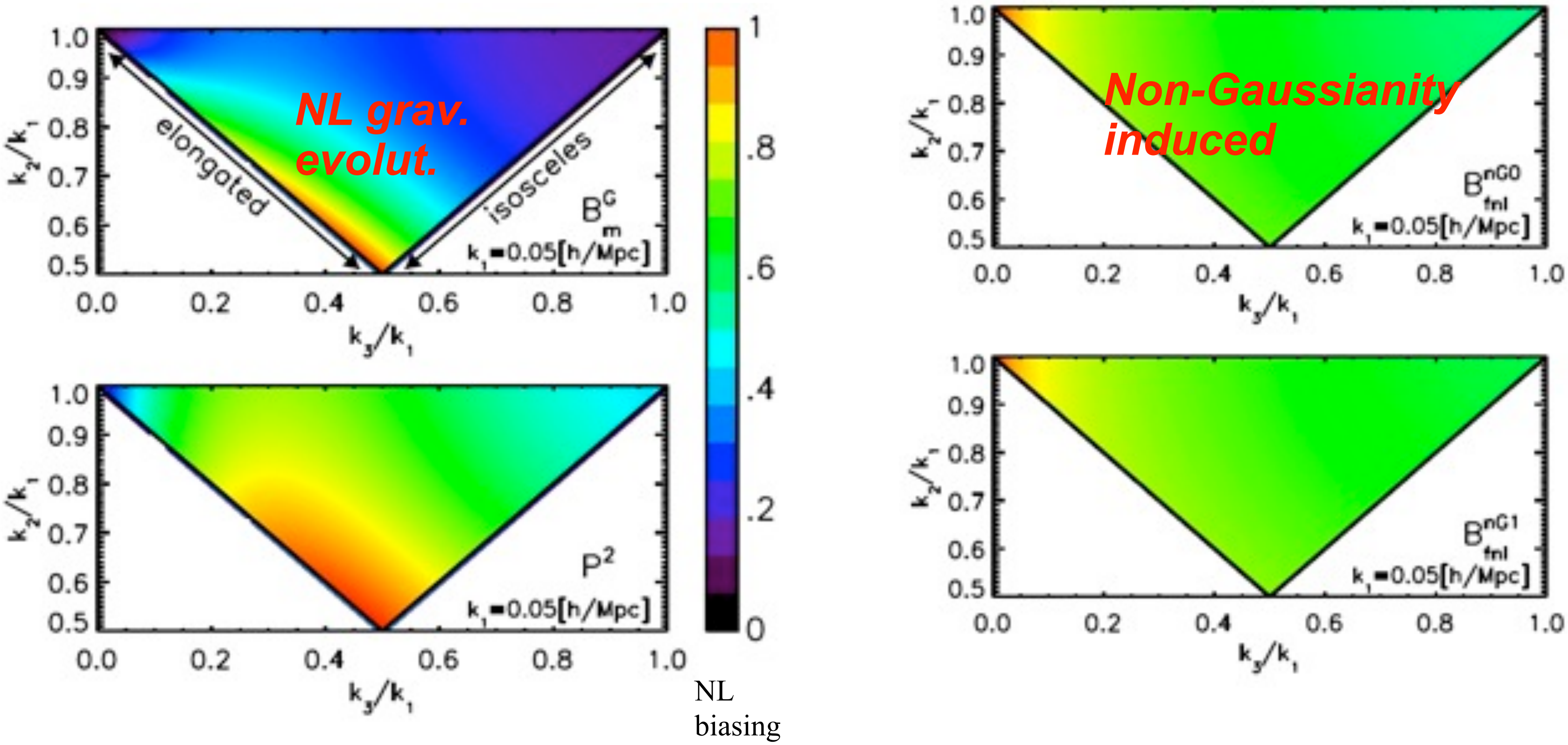


⟵ Inflation ⟶

Courtesy: Anze Slosar

BigBOSS: Bispectrum

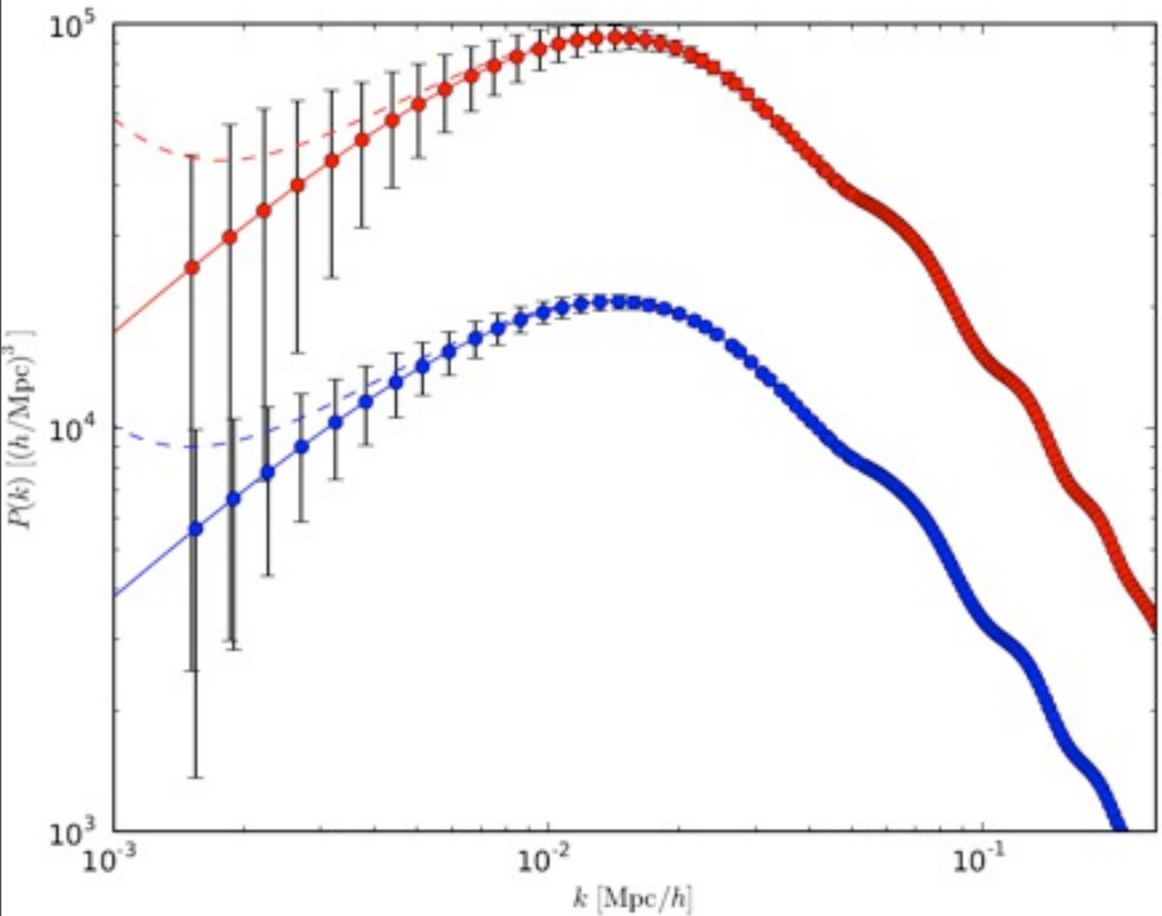
- Has big potential, in principle:
  - Measures **GROWTH -- yet another dark energy probe**
  - Can measure more general types of non-Gaussianity
  - Different contributions separated by different triangle configurations
  - Plots from Jeong & Komatsu:



The Ground-Based Stage IV BAO Experiment

BigBOSS

BigBOSS:
Inflation probe from Non-gaussianity



- Induces scale-dependent bias
- Big Volume helps!
- Interesting region around f_{NL} = 1
- Dashed lines predictions for f_{NL} = 5
- Systematics controlled by having multiple samples with different biases
- Selection function under control

BigBOSS allows systematics checks w/ multiple samples

JDEM-BAO satellite lacks this ***Courtesy: Anze Slosar***

I. BigBOSS science

II. Pilot data: DEEP2

II. Instrument

III. Imaging + Targets

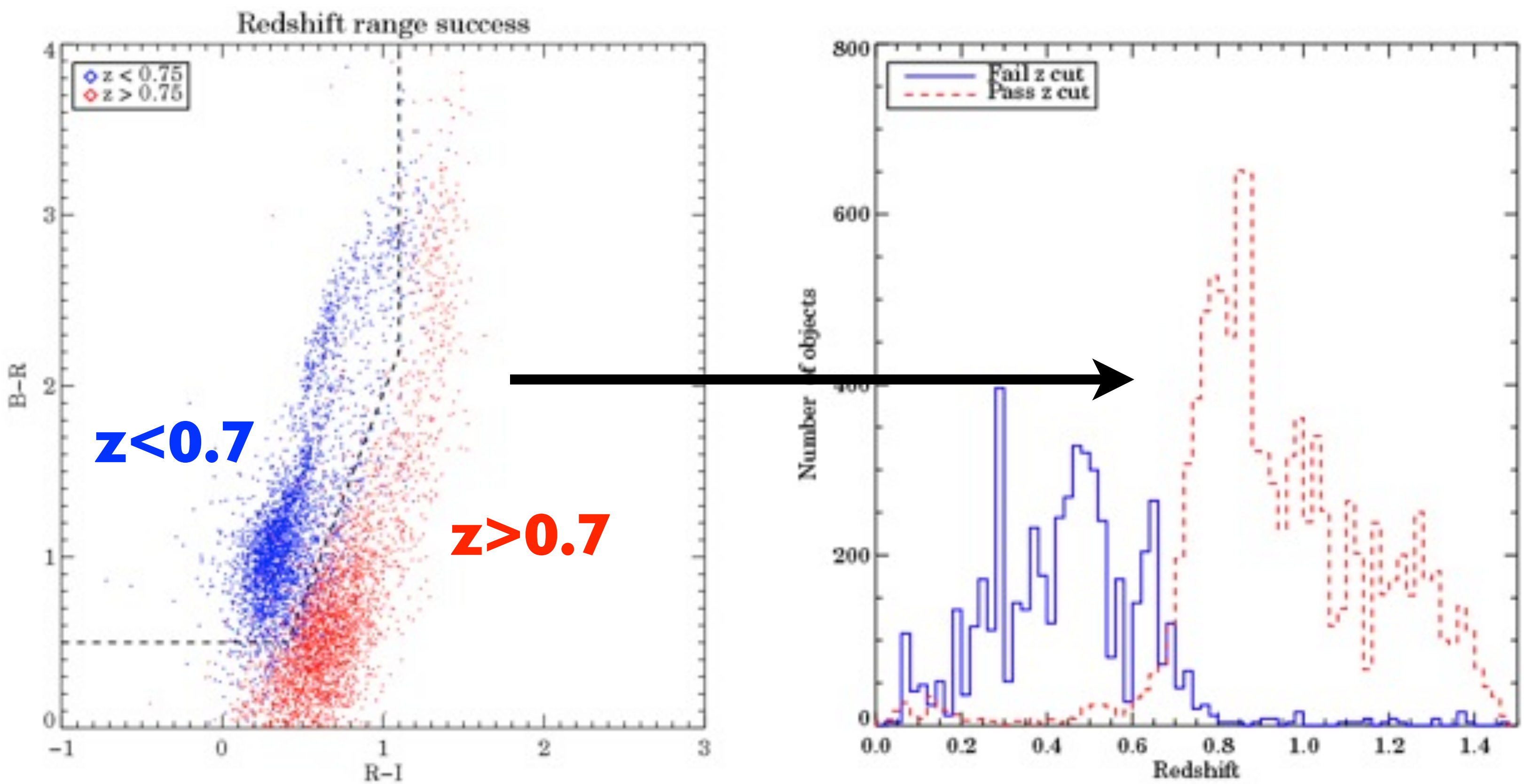
IV. Status

Pilot data from DEEP2
Emission-line galaxies 0.7<z<2

BRI targeting

Redshift from [O II] at R~5000

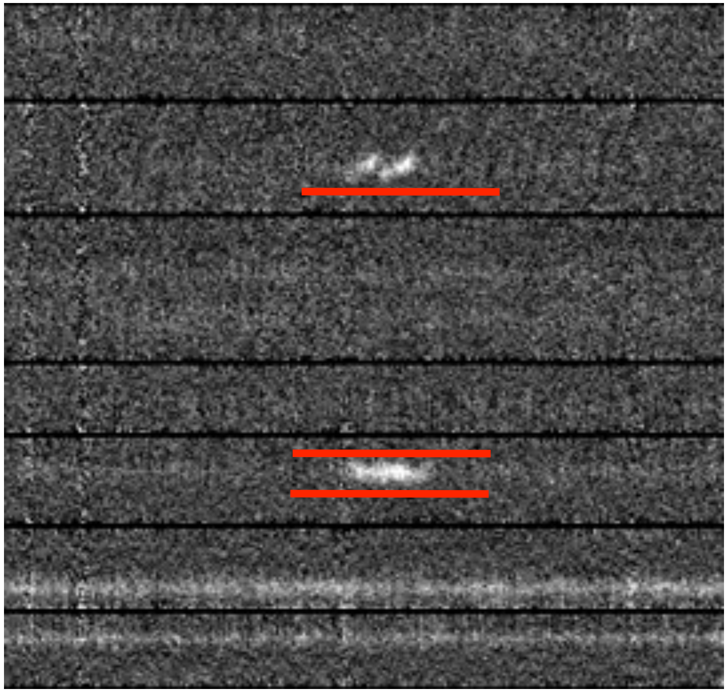
Much higher sampling than for BAO



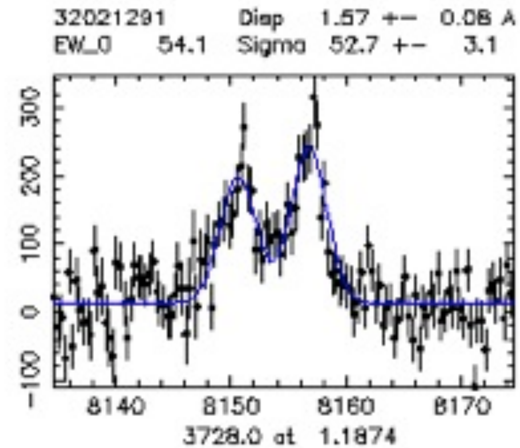
Pilot data from DEEP2
Emission-line galaxies 0.7<z<2

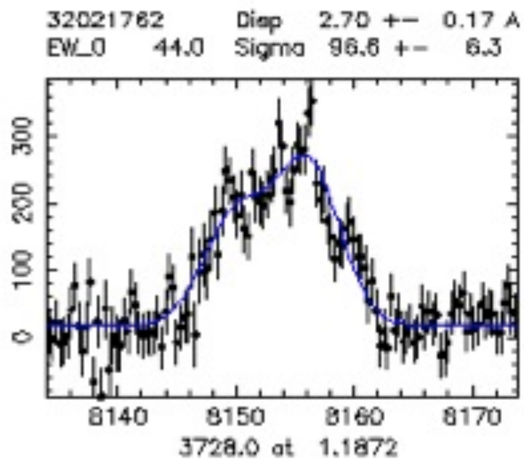
DEIMOS

DEEP2 measures more than z
BigBOSS only needs z's for brightest ~few %



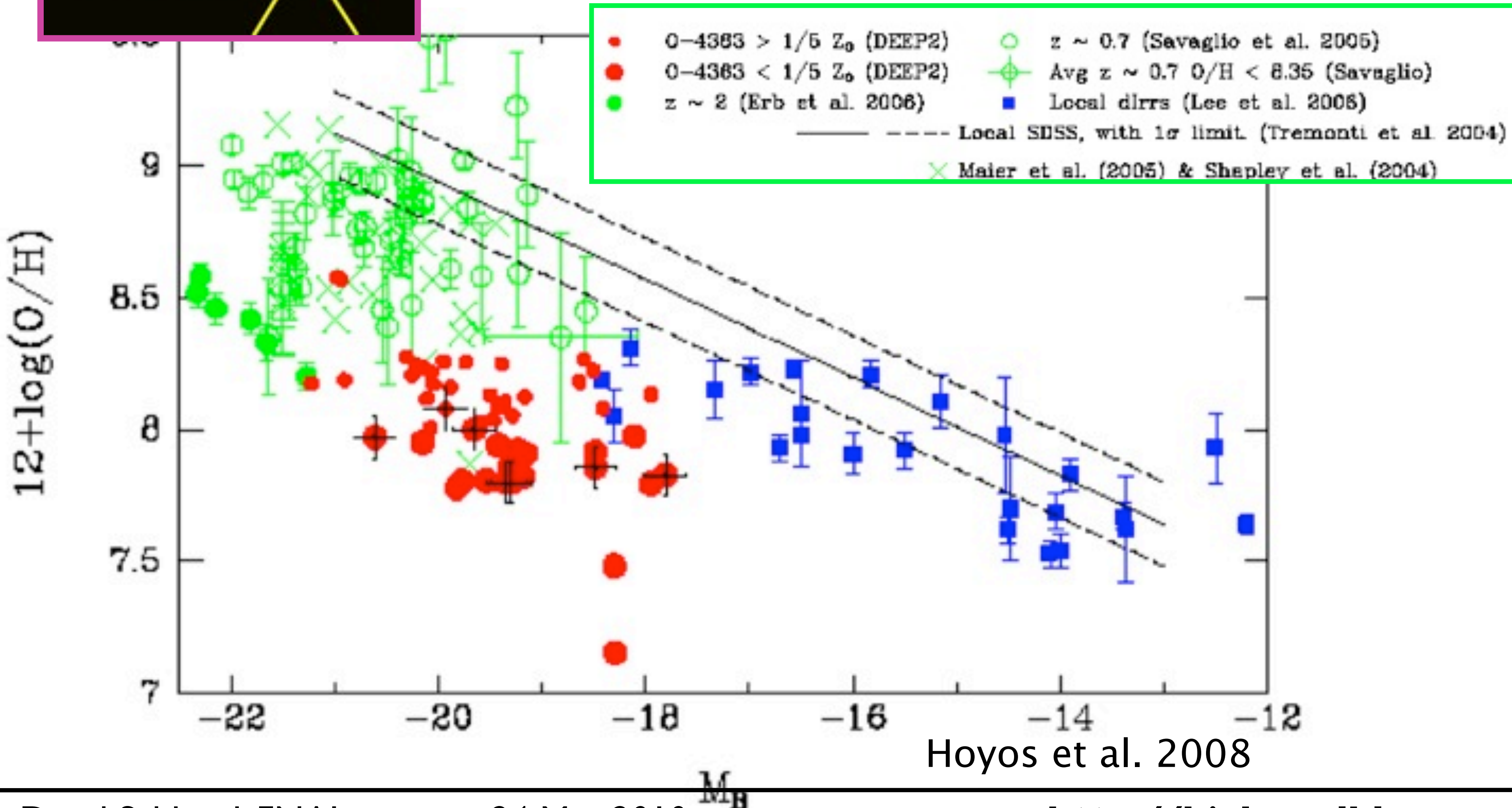
Weiner et al. 2004





Pilot data from DEEP2
Emission-line galaxies 0.7<z<2

Much more than a redshift!



Hoyos et al. 2008

I. BigBOSS science

II. Pilot data: DEEP2

II. Instrument

III. Imaging + Targets

IV. Status

Instrument: Telescope

Kitt Peak 4-m (Mayall) at Kitt Peak, Arizona

1.5-m f/5 secondary enables 3° FOV

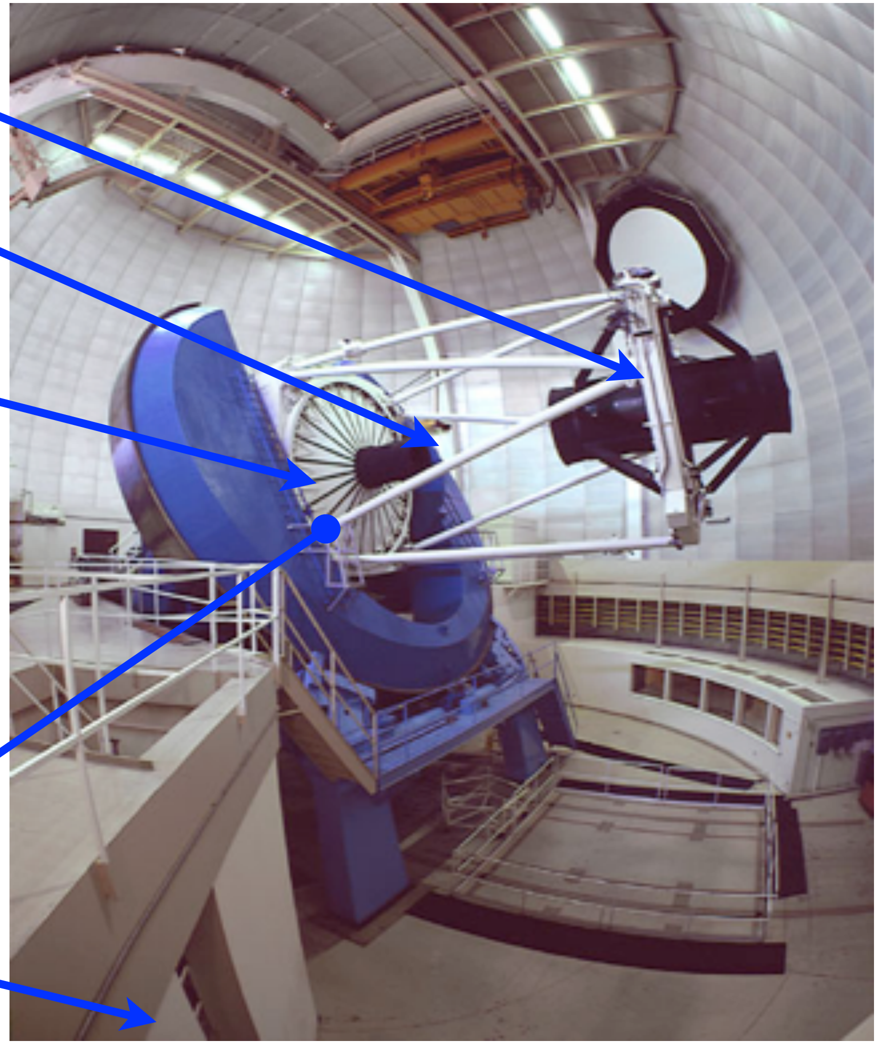
3-element corrector

5000 fiber positioners on 99-cm focal plane

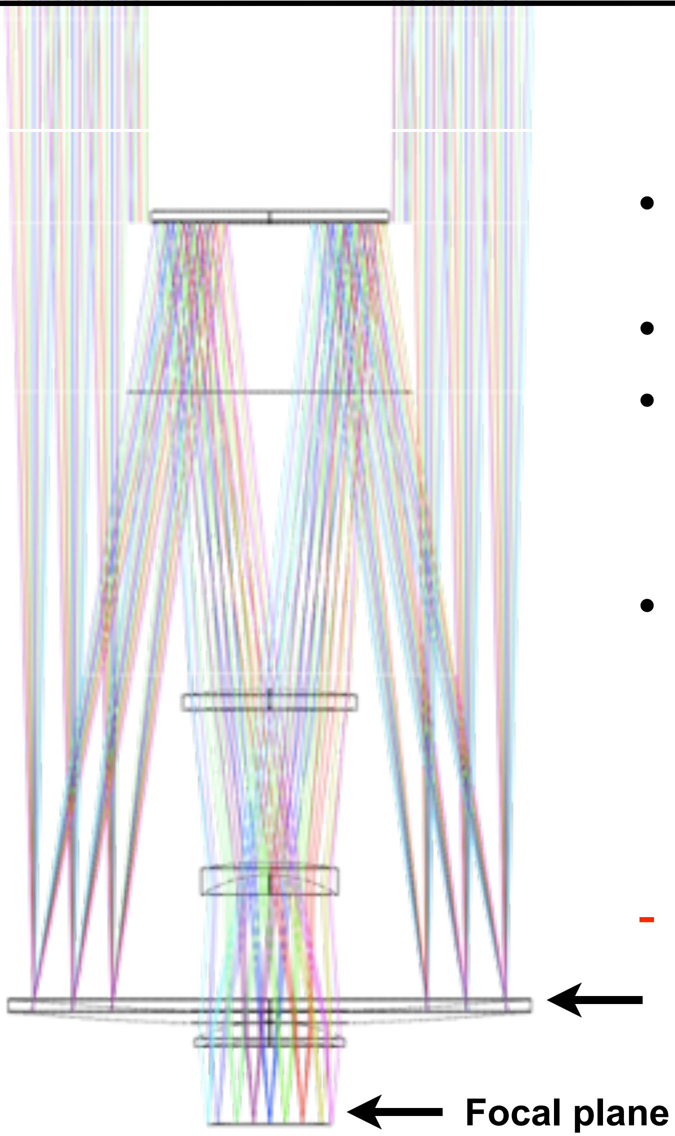
SDSS-inspired: simple, high-throughput

Fiber run (bare fibers)

10 spectrographs



Instrument:
Telescope optics



LBL Cassegrain design

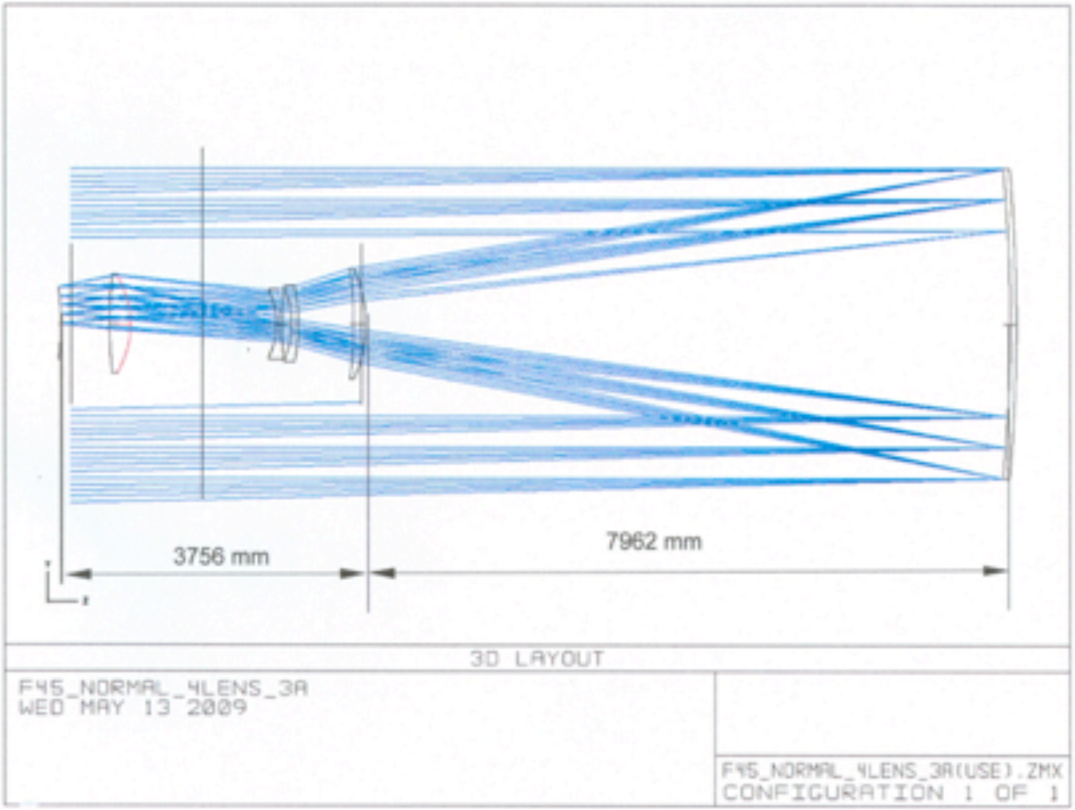
- Mayall is slow RC, making correction to **3º field** possible
- All magnification is in secondary
- Corrector lenses add no power
  - *Simple fused silica*
  - *No CaF*
- Manufacturing feasibility verified by the University of Arizona College of Optical Sciences
  - *Less challenging than previous optics, using profilometry + interferometry*
- Identical optics work at KPNO 4m + CTIO 4m

The Ground-Based Stage IV BAO Experiment
BigBOSS

Instrument: Telescope optics

Alternative designs: NOAO prime focus

Prime Corrector: Basic Design, F/4.5



Design highlights:

Four corrector lenses.

F-number: 4.5

FOV: 3°

Lens1 aperture radius: 680 mm

Three aspheric surface, and the largest aspheric sag < 1.85 mm

Geometric throughput: 72%

Equivalent telescope diameter: 3.25 m.

Etendue: 58.53 m^2 deg^2

Instrument: Telescope optics

If we don't do this, someone else will!

4-m class telescopes:

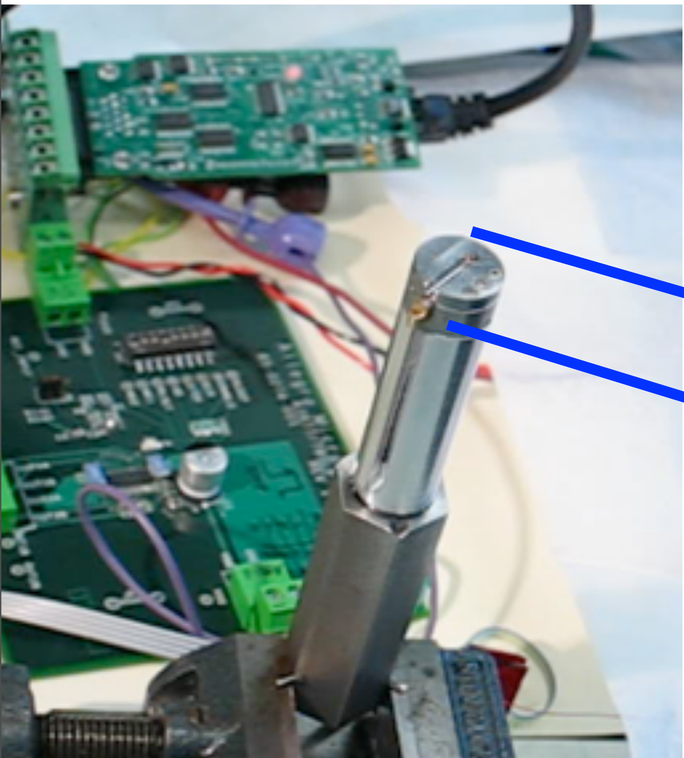
KPNO 4-m
CTIO 4-m
CFHT 3.6-m
Calar Alto 3.5-m
ARC 3.5-m (Apache Point)
WIYN 3.5-m (Kitt Peak)
Discovery Channel 4.2-m
WHT 4.2-m
ESO 3.6-m
SOAR 4.2-m
UKIRT 3.8-m
Galileo 3.58-m
ESO NNT 3.58-m
VISTA 4-m
AAT 3.9-m

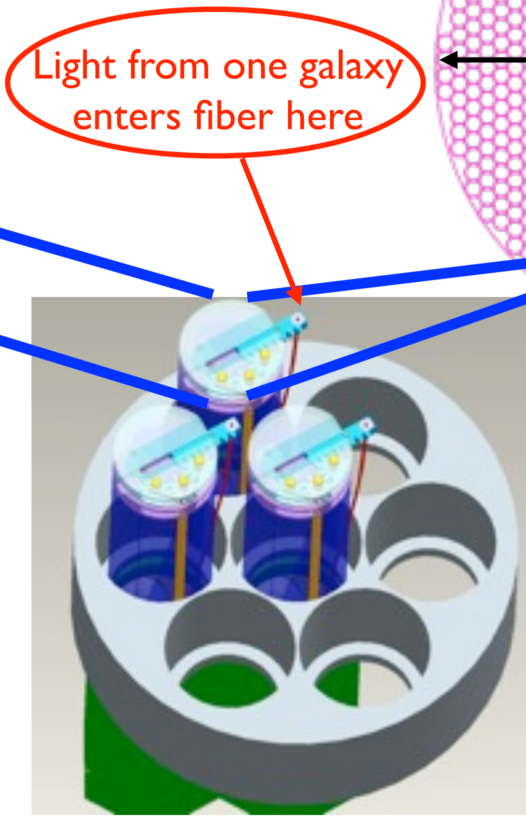
3-deg possible

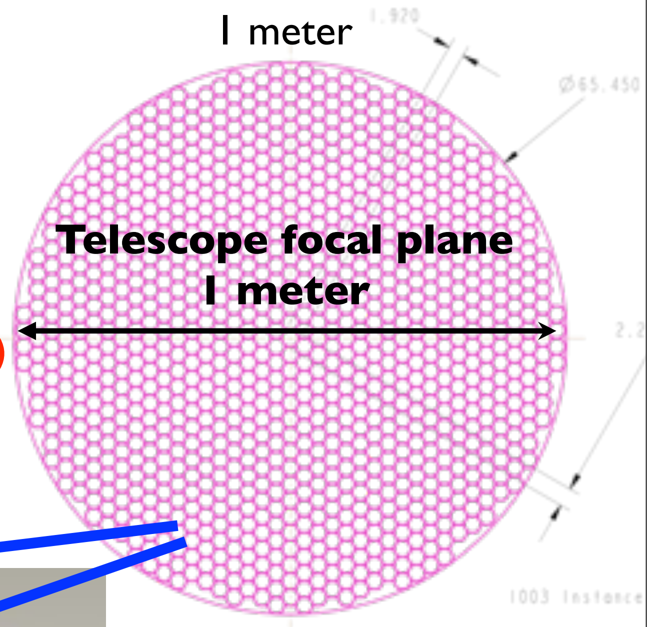
2-deg exists

Instrument:
Fiber positioners x 5000

LBNL fiber positioner





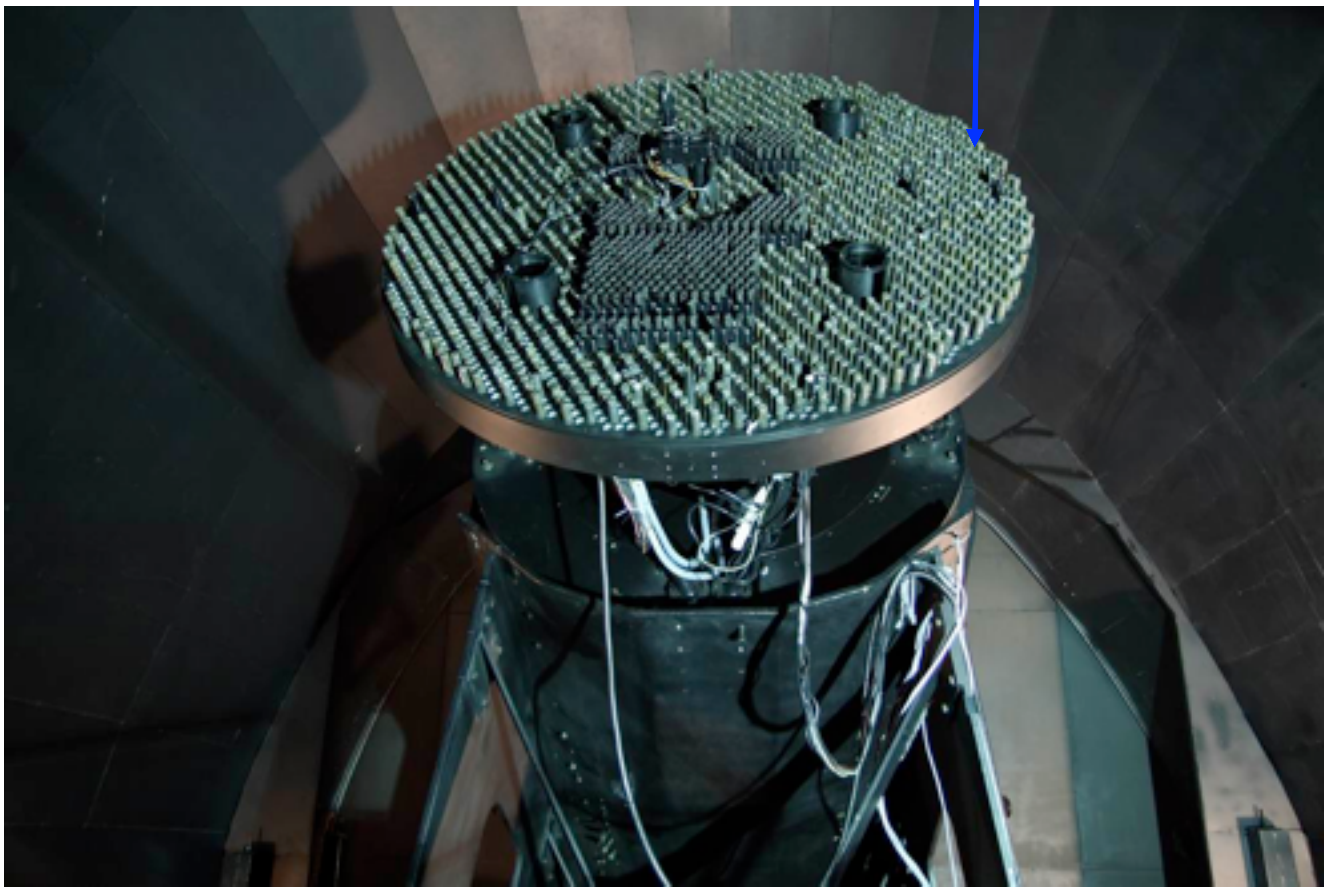


Instrument: Fiber positioners x 5000

Collaboration with USTC in Hefei, China

Experience building 4000 LAMOST fiber positioners
2 rotation axes, 25.4 mm center-to-center spacing

Light from one galaxy enters fiber here

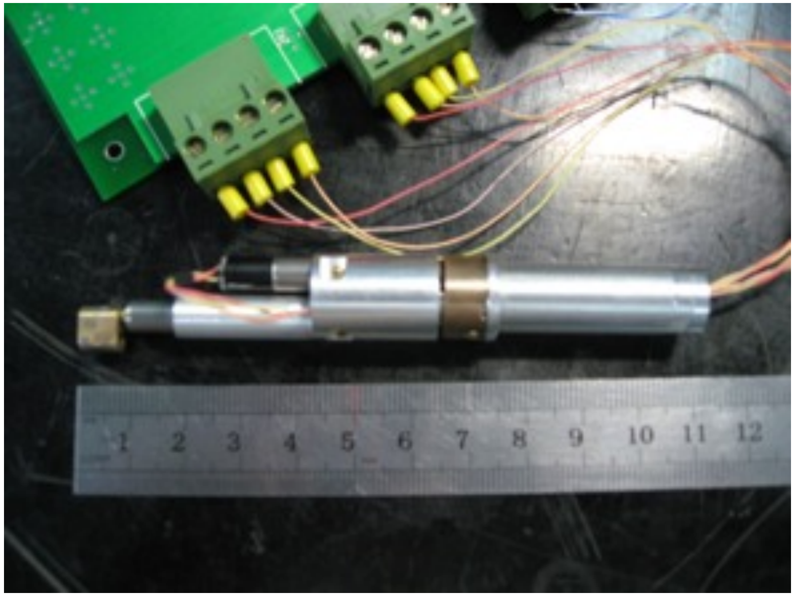


Instrument: Fiber positioners x 5000

Collaboration with USTC in Hefei, China

First prototype with 15 mm spacing (4000 fibers)
Next prototype with 12 mm spacing (5000+ fibers possible)

BigBOSS prototype #1 !!
30 Sep 2009

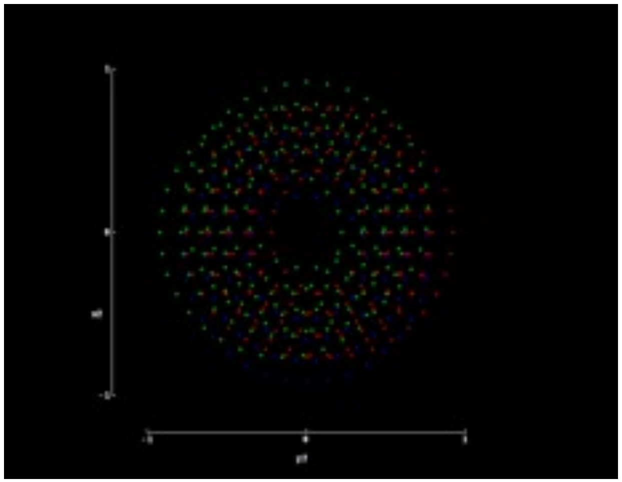


Instrument: FiberViewCam

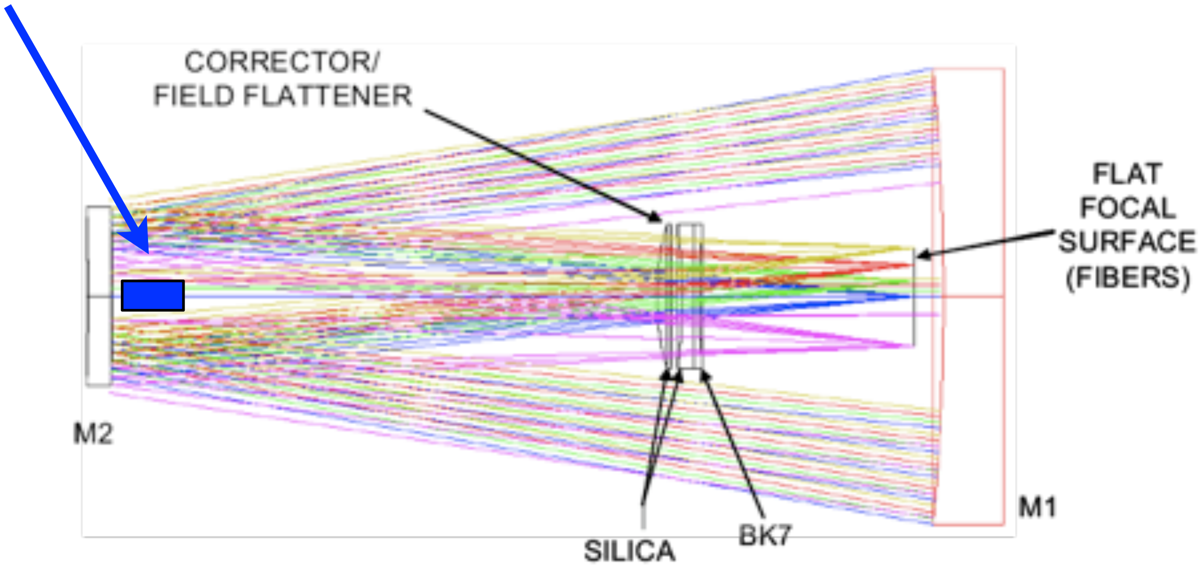
Image fibers from near M2

Calibrates positions of all the fiber "zero positions"

Back-light fibers within the spectrograph
9k x 9k camera sits in optically-unused spot near M2

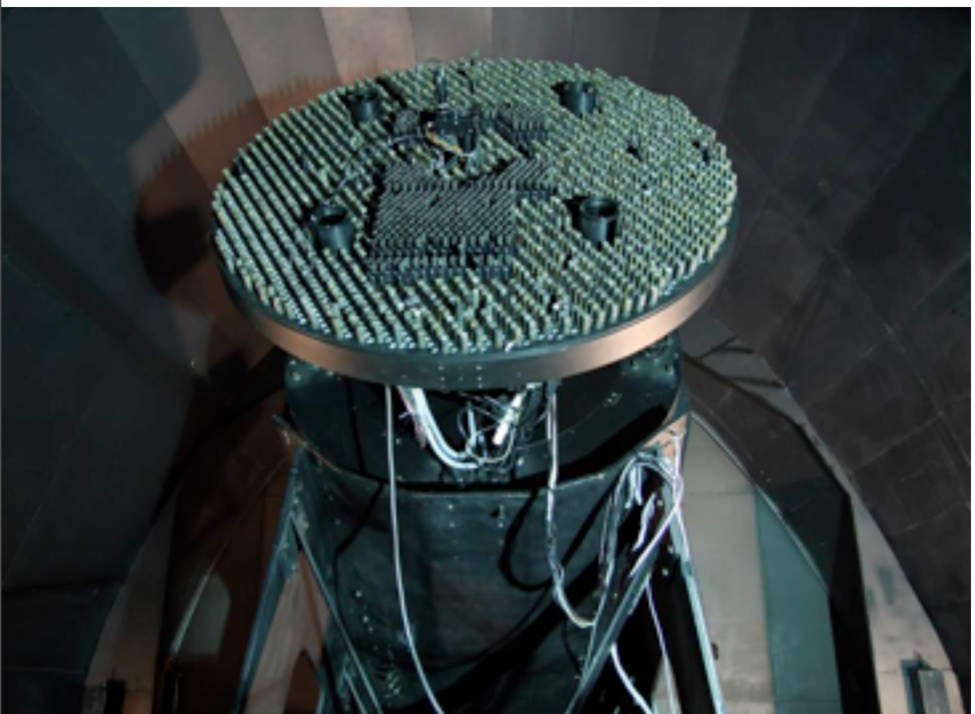


Inner 40 cm of M2 unused optically



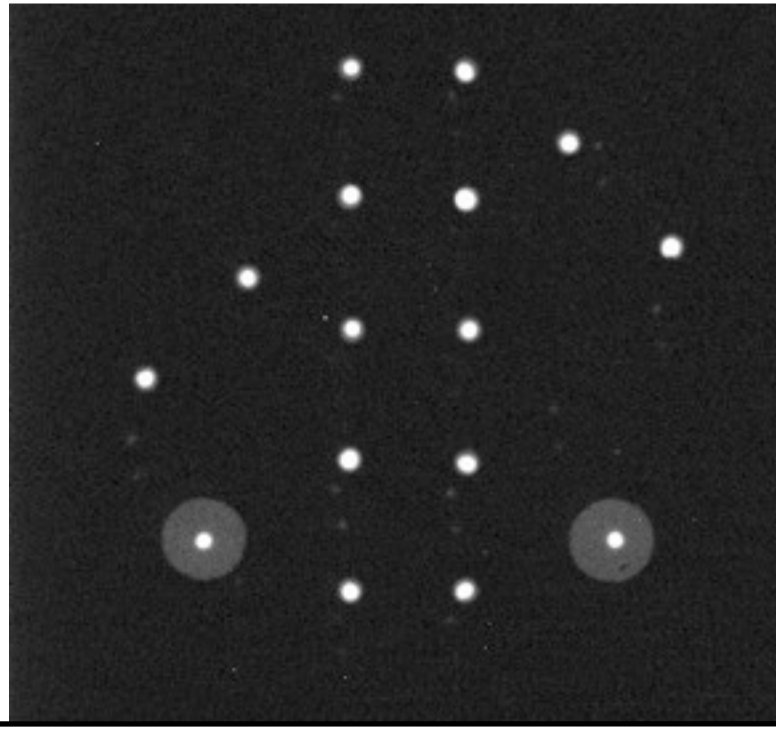
Instrument: Acquistion + guiding

LAMOST uses 4 CCD cameras



SDSS/BOSS uses 16 coherent (plastic!) fiber bundles

Some are +/- 400 microns from focus to guide in focus



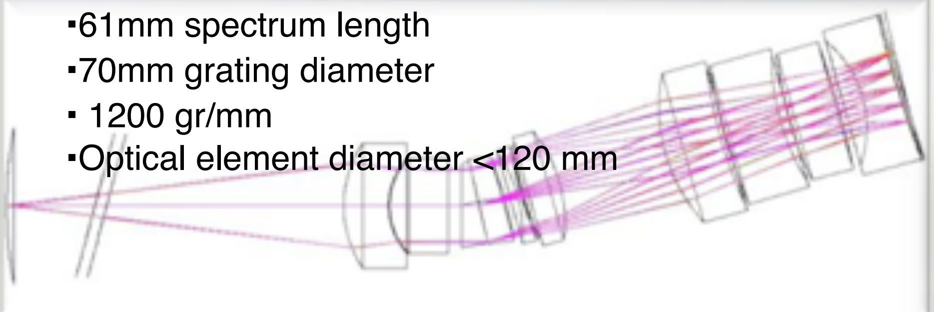
The Ground-Based Stage IV BAO Experiment
BigBOSS

Instrument: Spectrographs x 10

Conceptual design, Eric Prieto (LAM/France)
Beamsplitter + 3 refractive collimators

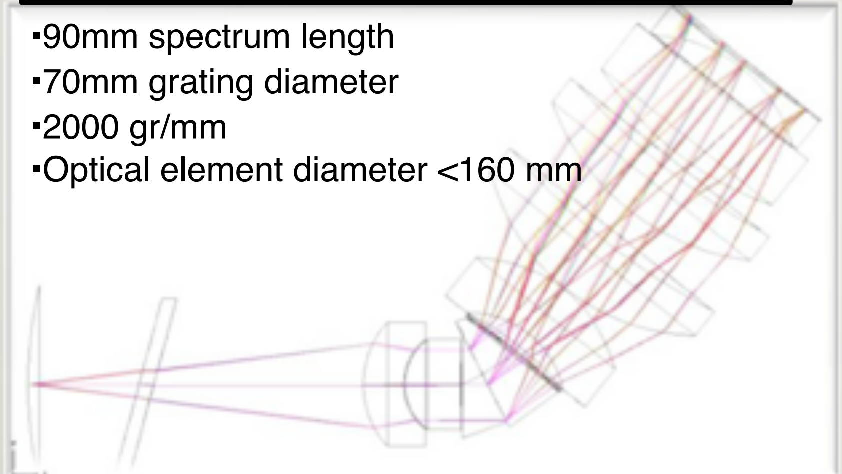
Blue "QSO Lyα channel"
3400-5500 Å at R~4000
e2v CCDs

- 61mm spectrum length
- 70mm grating diameter
- 1200 gr/mm
- Optical element diameter <120 mm



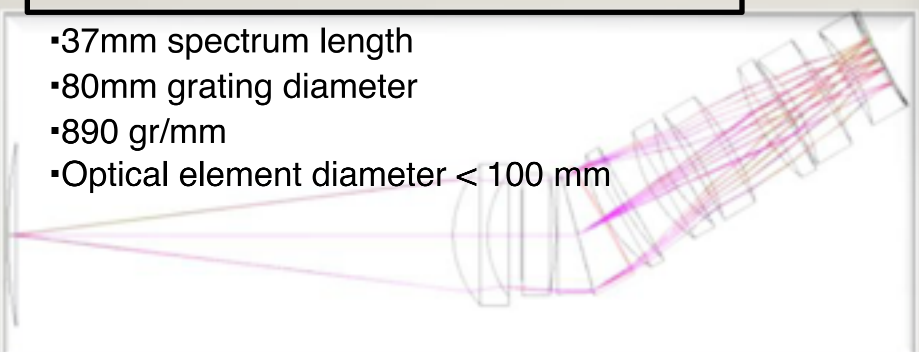
Visible "supernova/QSO channel"
5500-8000 Å at R~3500
LBL CCDs

- 90mm spectrum length
- 70mm grating diameter
- 2000 gr/mm
- Optical element diameter <160 mm



Red "galaxy channel", R>5000
8000-11,000 Å at R~5000
LBL "Extreme Silicon"

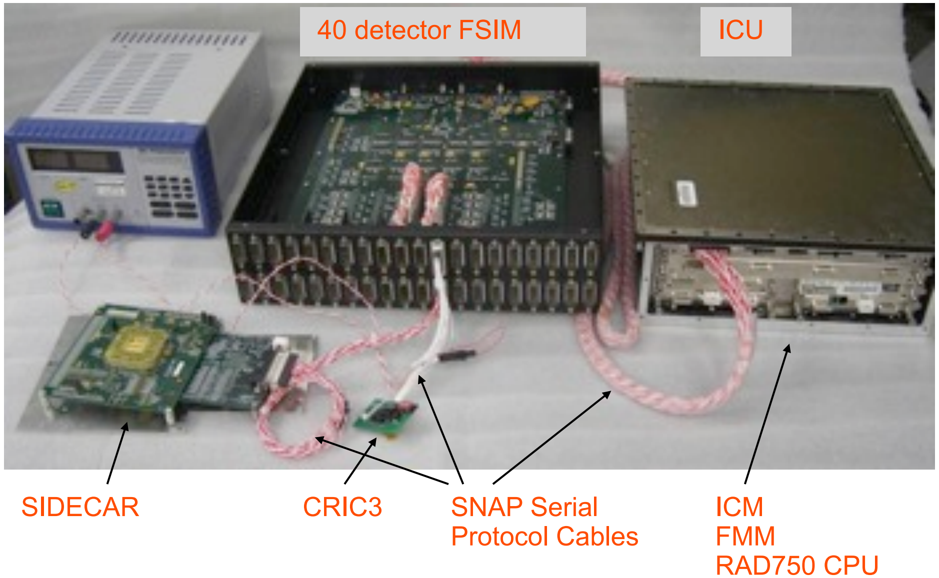
- 37mm spectrum length
- 80mm grating diameter
- 890 gr/mm
- Optical element diameter < 100 mm



Instrument: Detector readout system

Developed by Stanford/SLAC for SNAP/JDEM satellite
Control 40 CCDs and HgCdTe in same module

Prototype readout system



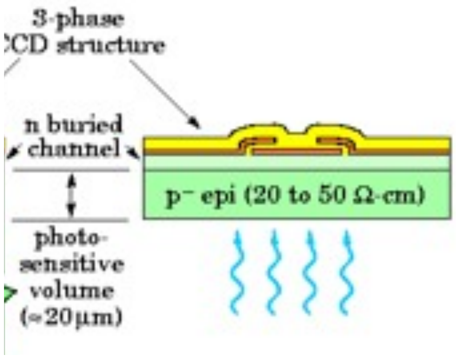
GLAST memory board populated with **FLASH**

FSIM interface

PPC CPU

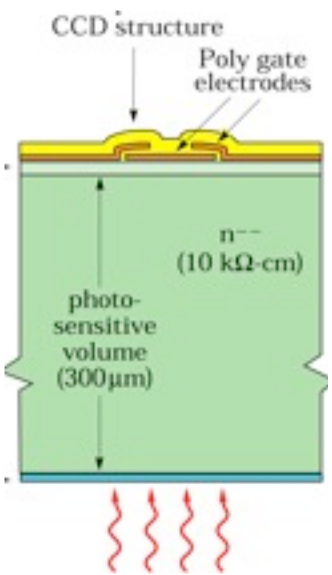
Instrument:
"Extreme silicon"

Red "galaxy" channel
R&D to use *only* silicon at λ>1 micron



Standard CCD is thin (~10 μm)

Poor red response



Fully-depleted CCD is thick

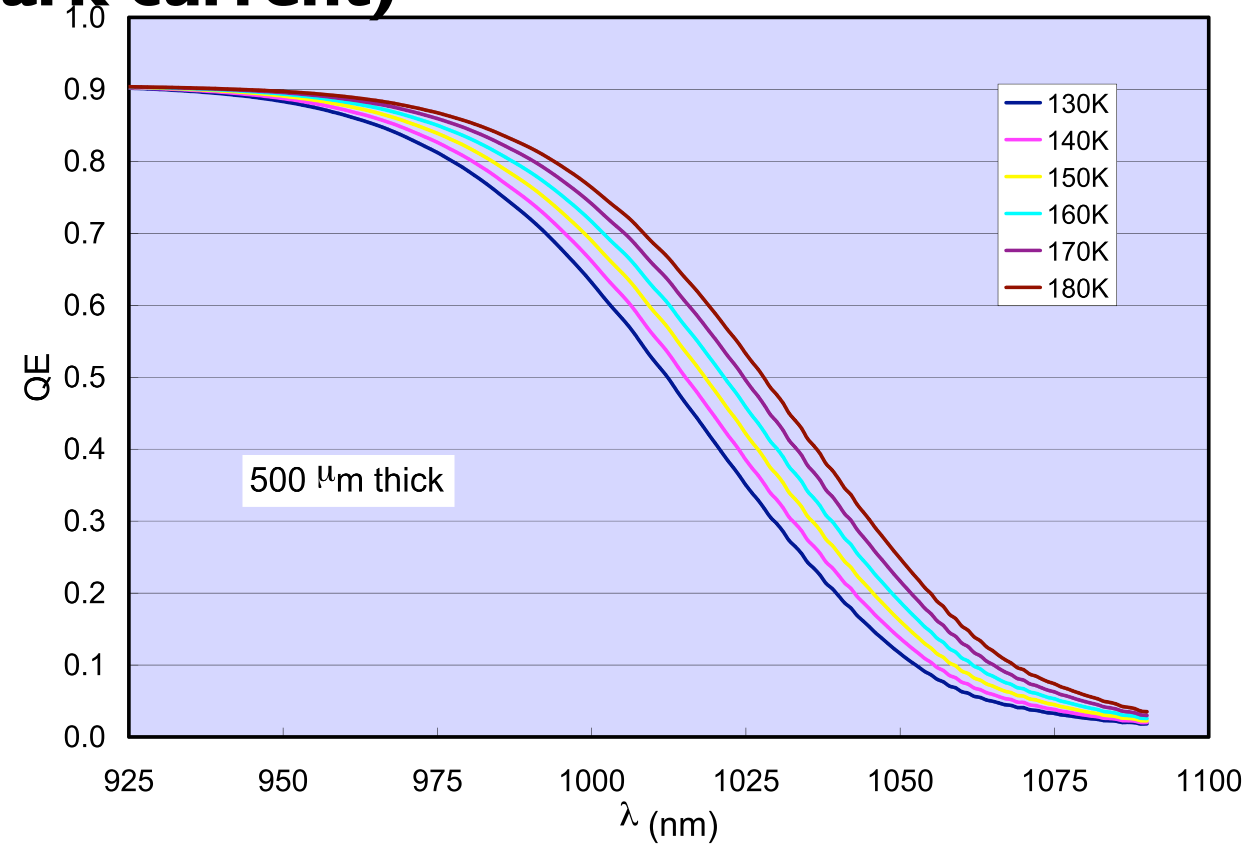
Excellent red response

➜ 650 μm thick !!

Instrument:
“Extreme silicon”

R&D to use *only* silicon at λ>1 micron

Q.E. is temperature dependent
(Trade vs. dark current)

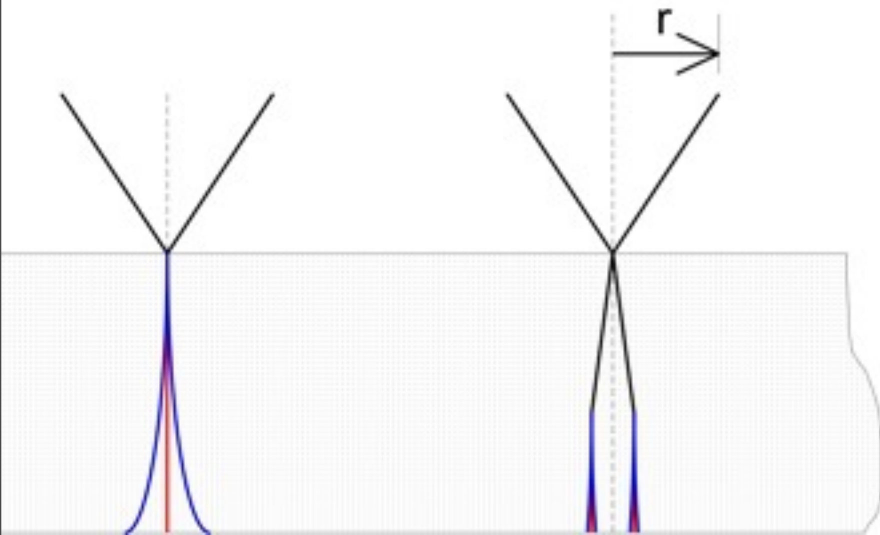


Instrument:
"Extreme silicon"

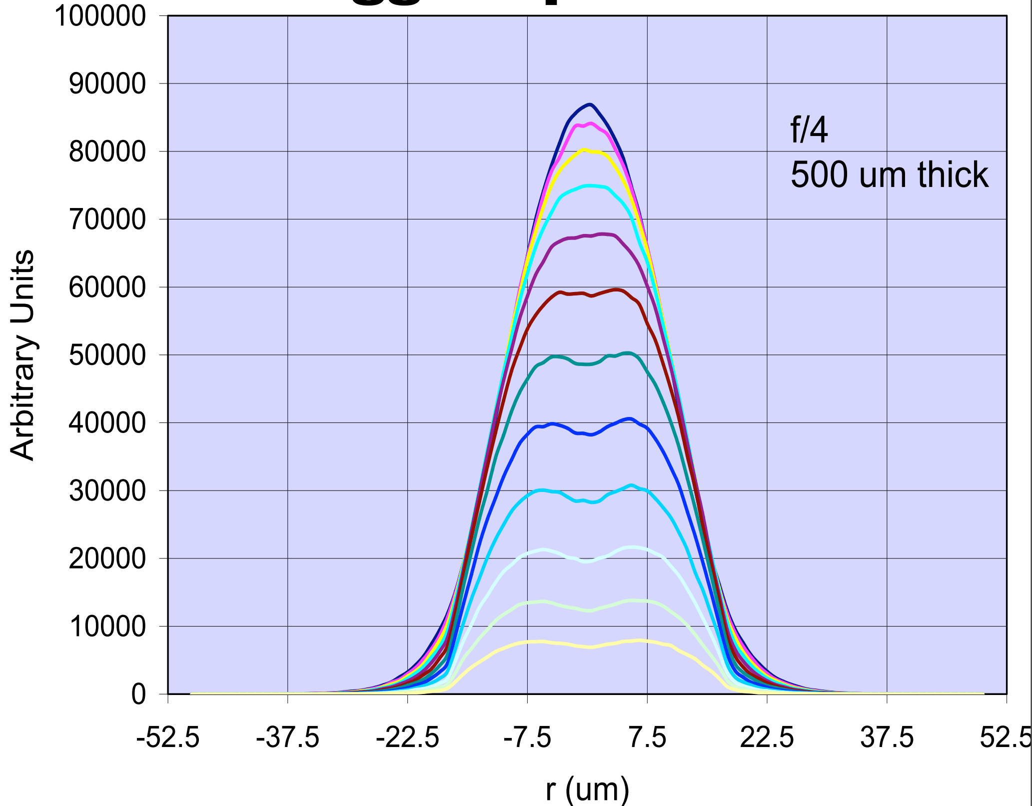
R&D to use *only* silicon at λ>1 micron

Charge diffusion through 650 μm of silicon

Diverging beam + diffusion = bigger spots



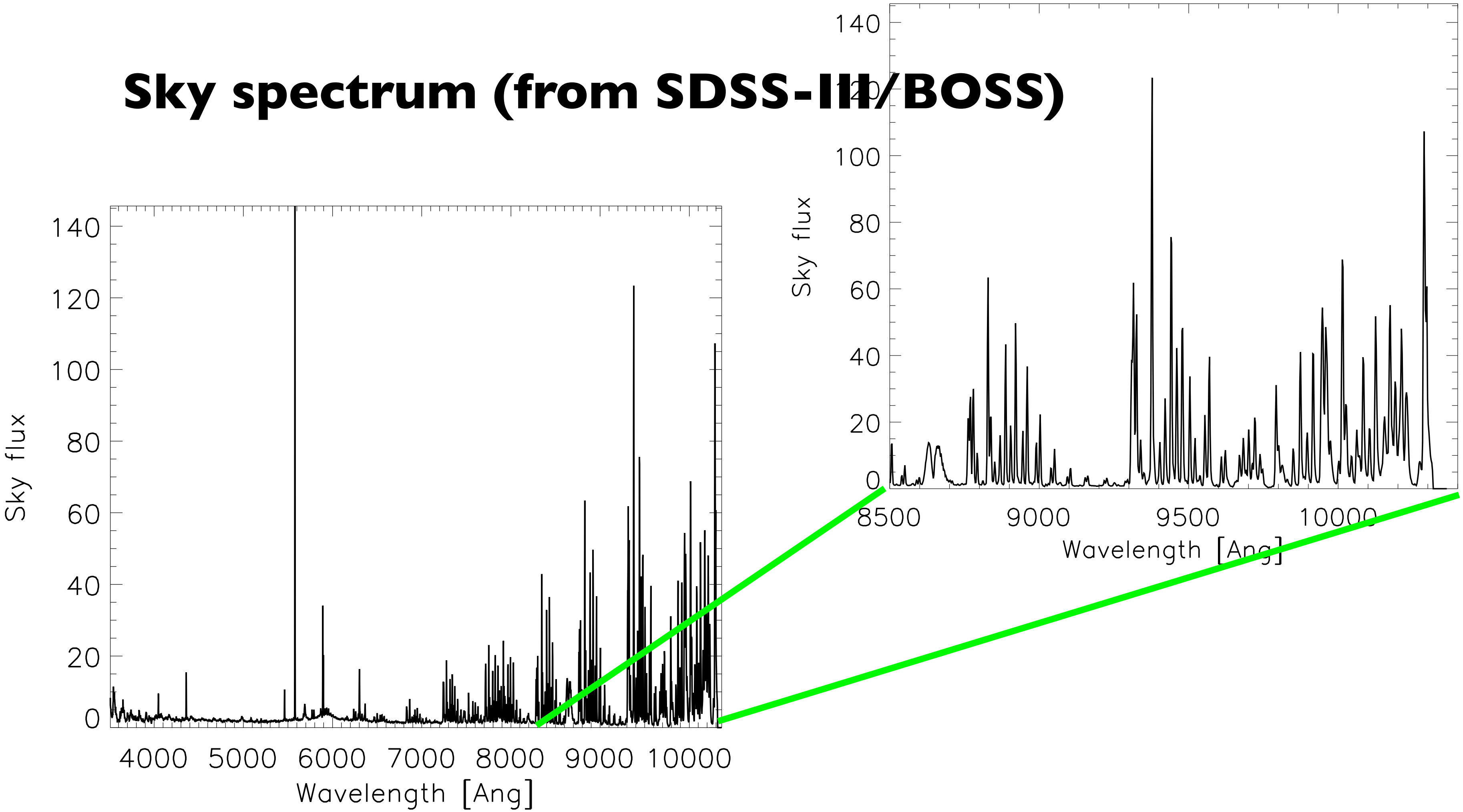
Si index of refraction=3.6



Instrument: Spectrographs x 10

Instrument designed to be a "BAO spectrograph"
Detect emission-line galaxies at $z \rightarrow 1.7$

Sky spectrum (from SDSS-III/BOSS)



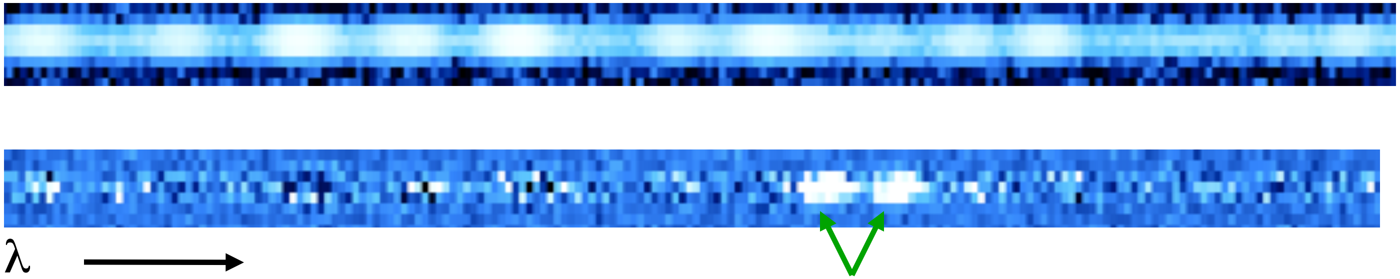
Instrument: Spectrographs x 10

Instrument designed to be a "BAO spectrograph"

Detect emission-line galaxies at z→1.7

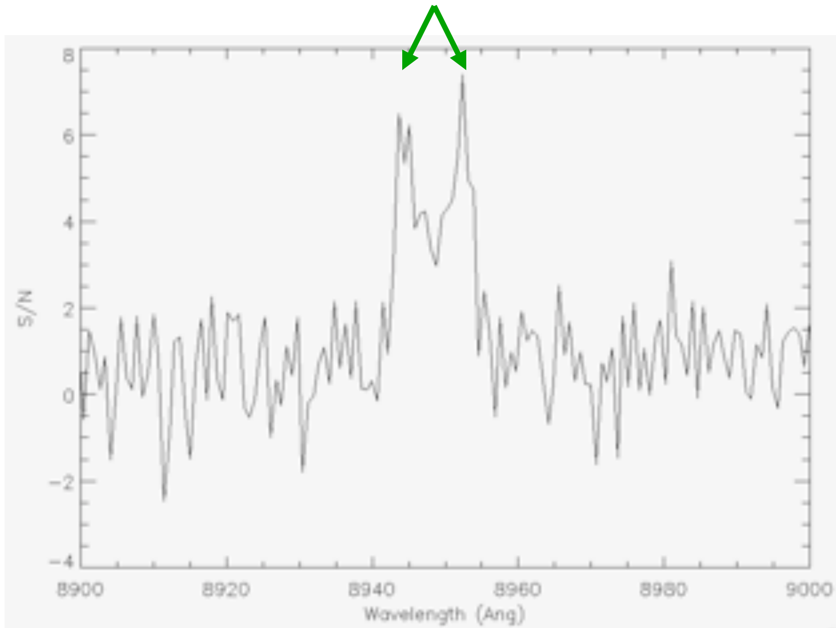
Observed Spectrum

Sky-Subtracted Spectrum



λ →

[OII]λ3726, λ3729 @ z=1.4

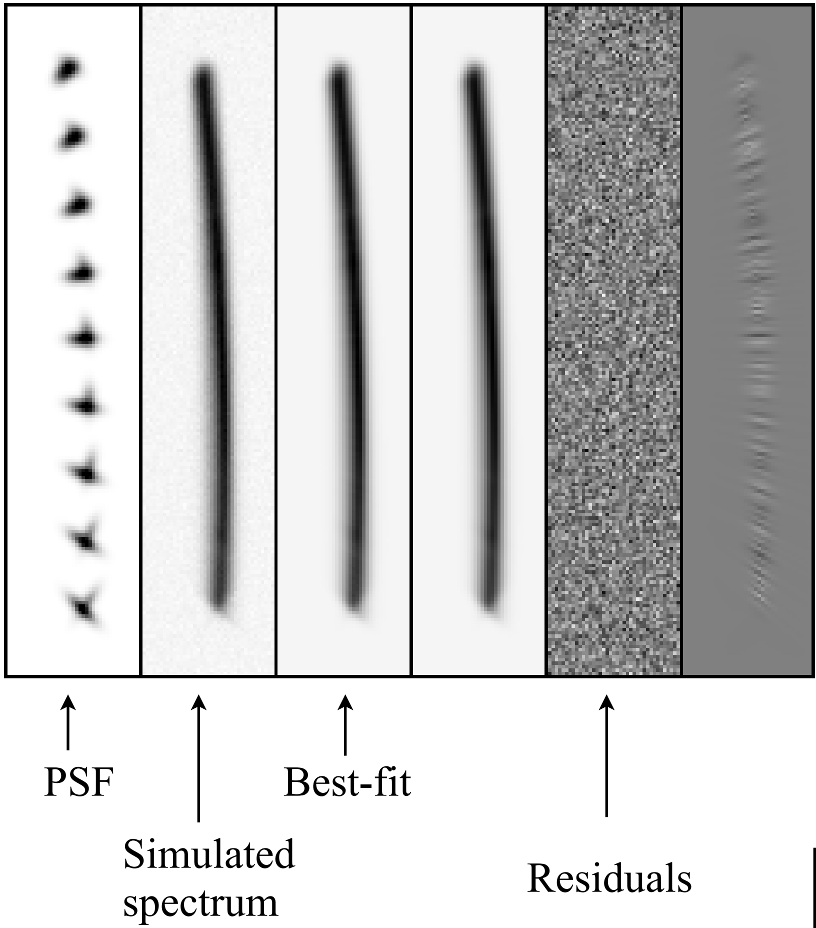


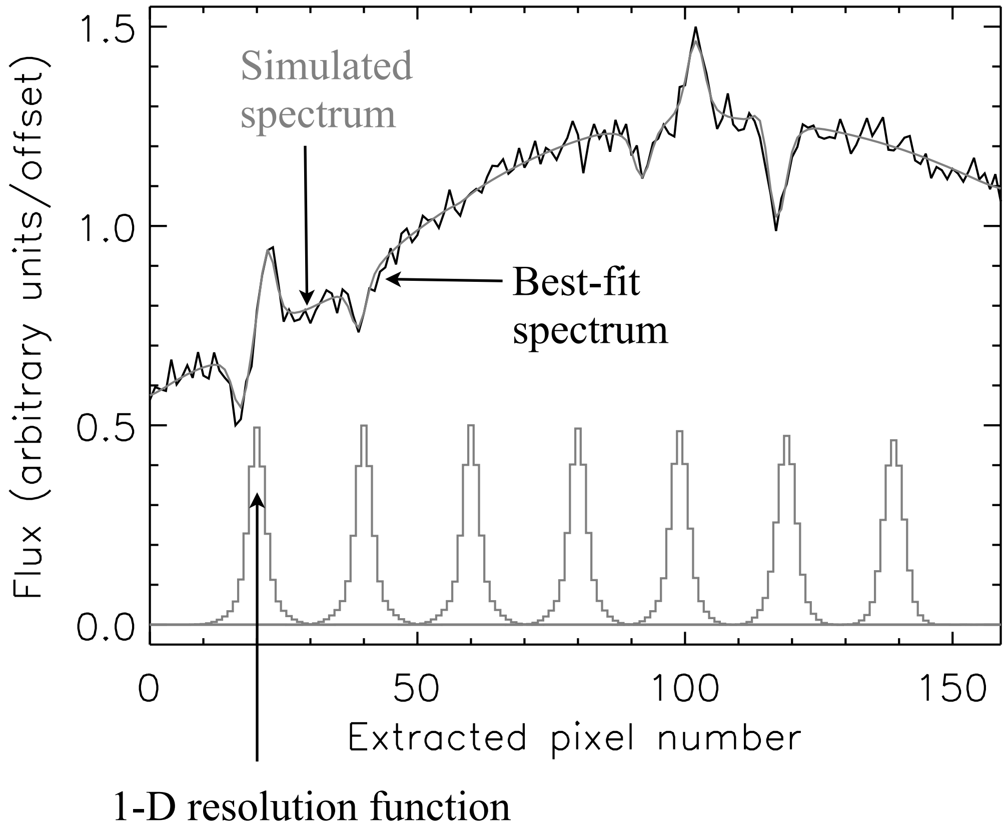
Resolution > 5000
- **➜ Split [O II] line**
- **➜ Work between sky lines**

Same as DEEP2 survey

Instrument: Spectrographs x 10

Next-generation fiber spectroscopy == "Spectro-Perfectionism"
(Bolton & Schlegel, astro-ph/0911.2689, in press)





If the 2-D PSF is asymmetric, you ***cannot*** have both a symmetric 1-D PSF and independent pixels

I. BigBOSS science

II. Pilot data: DEEP2

II. Instrument

III. Imaging + Targets

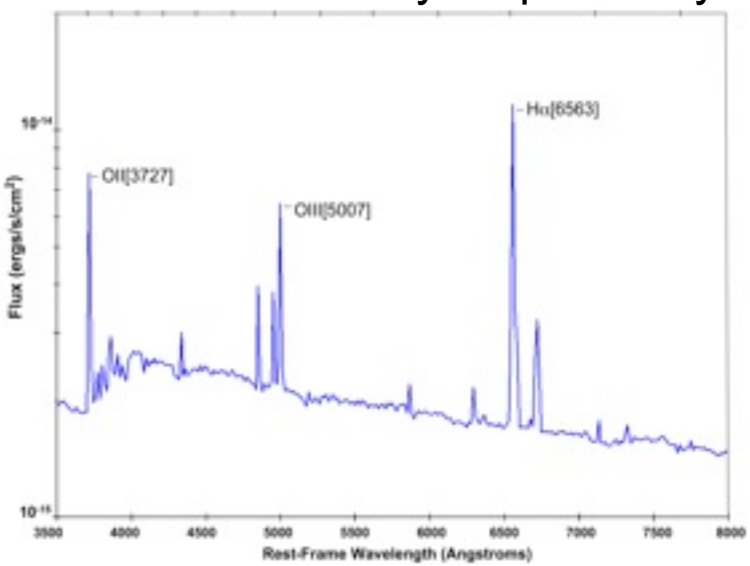
IV. Status

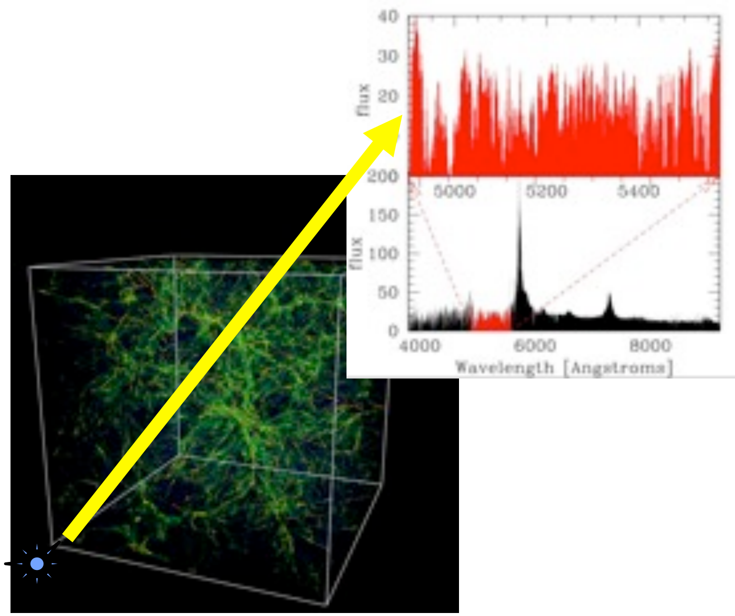
The Ground-Based Stage IV BAO Experiment
BigBOSS

Targets:
"Easy target survey"

- **Luminous Red Galaxies (LRGs):**
  - Selected to z<1
  - Efficient BAO tracers due to large bias
- **Emission-line galaxies:**
  - Selected 0.7<z<2.0 at source density of dn/(dz deg^2)=2000
  - Redshifts from [O II], [O III] emission lines, R~5000
- **QSOs:**
  - Selected 2<z<3.5
  - 3-D density map from Ly-alpha forest

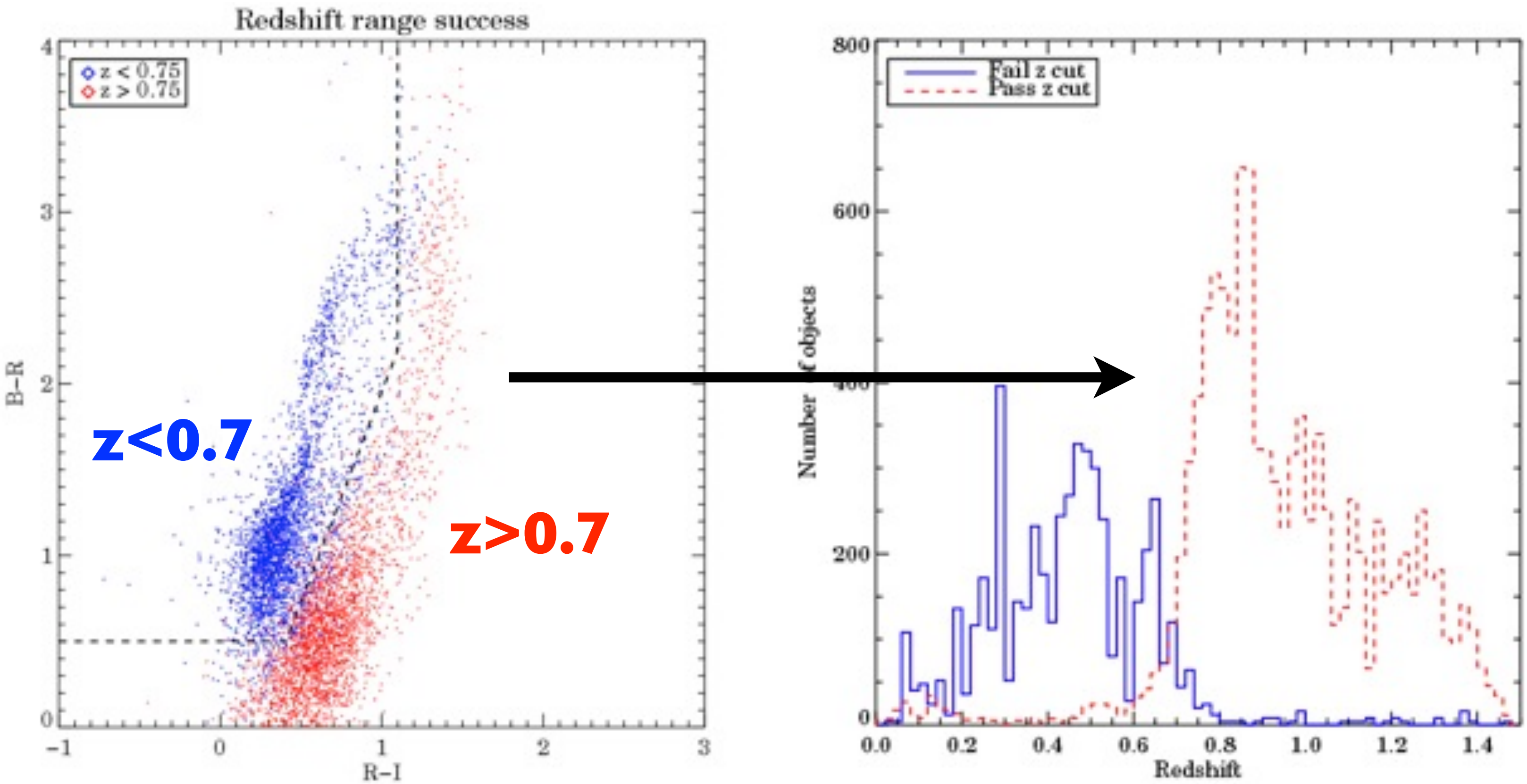
Questions:
Add 1<z<2 QSOs?



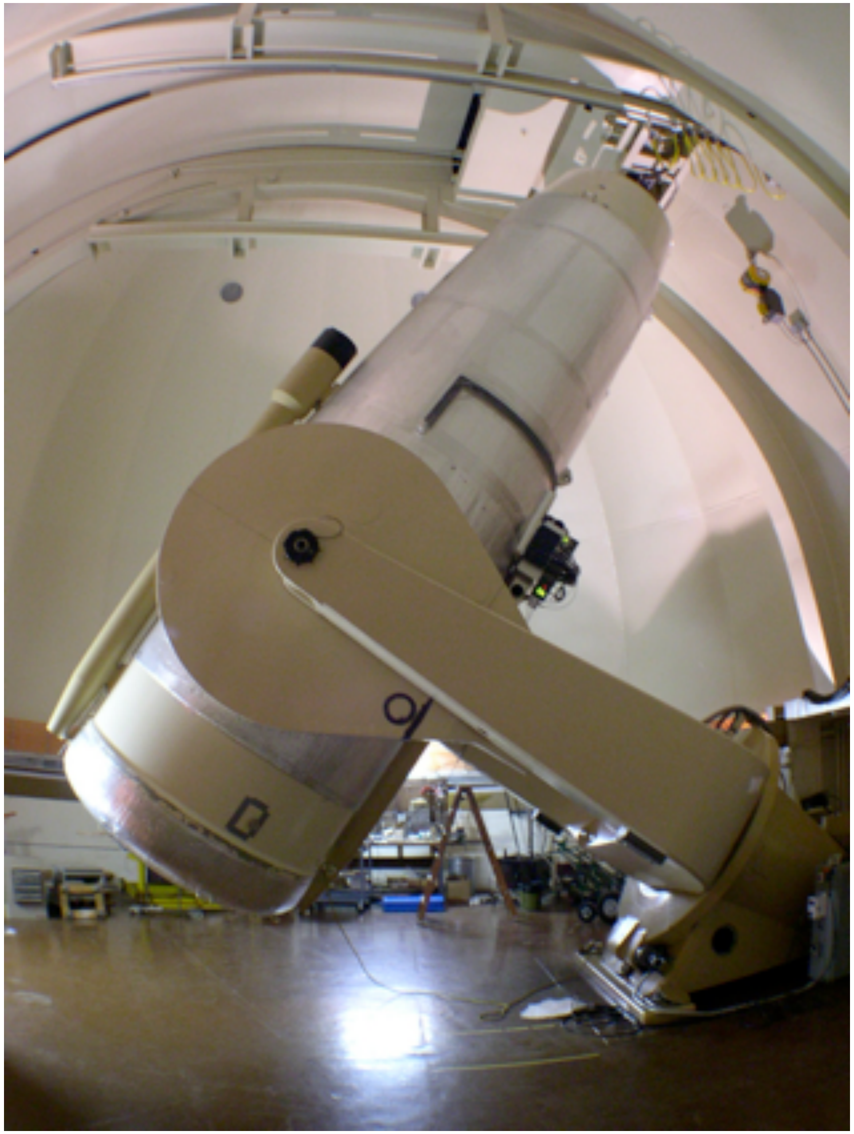


Targets: Emission-line galaxies 0.7<z<2

DEEP2 + zCOSMOS surveys demonstrate targeting [O II] emitters
No need for photo-z's



Targets:
Emission-line galaxies 0.7<z<2

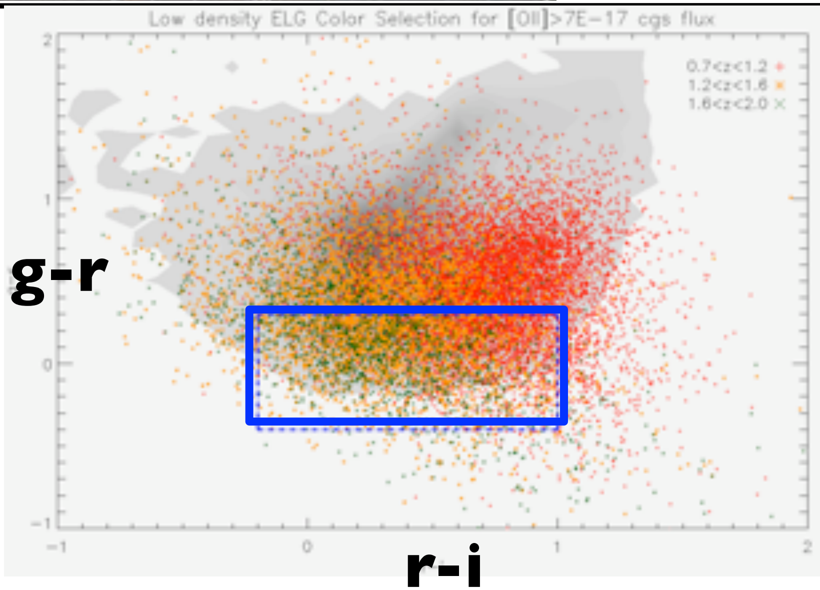


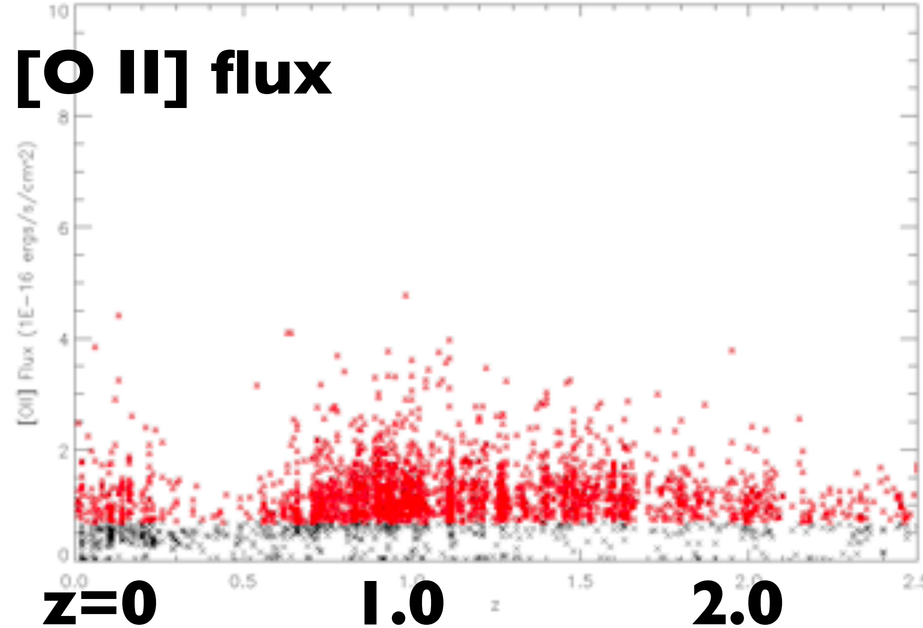
Palomar Transient Factory

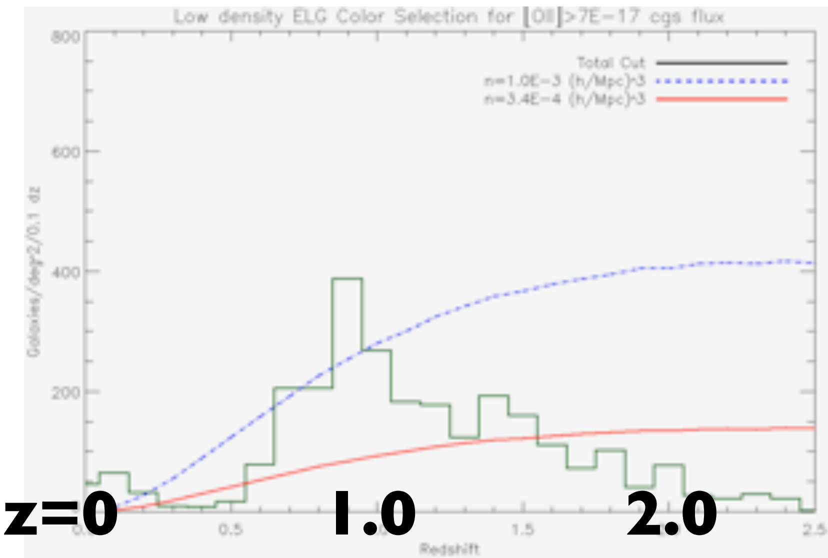
g+r imaging (3 hrs)
i-band needed elsewhere

The Ground-Based Stage IV BAO Experiment
BigBOSS

Targets: Emission-line galaxies 0.7<z<2







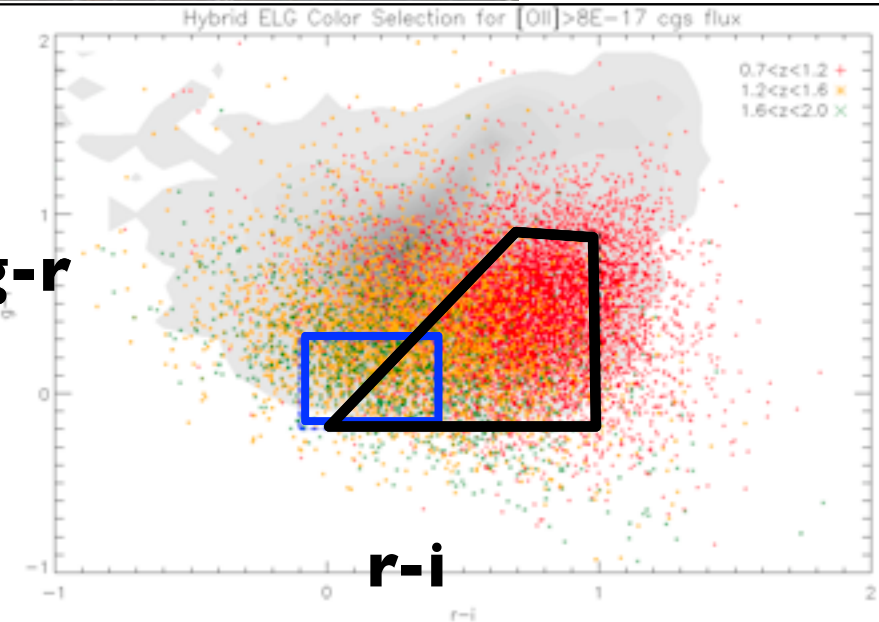
BAO sample

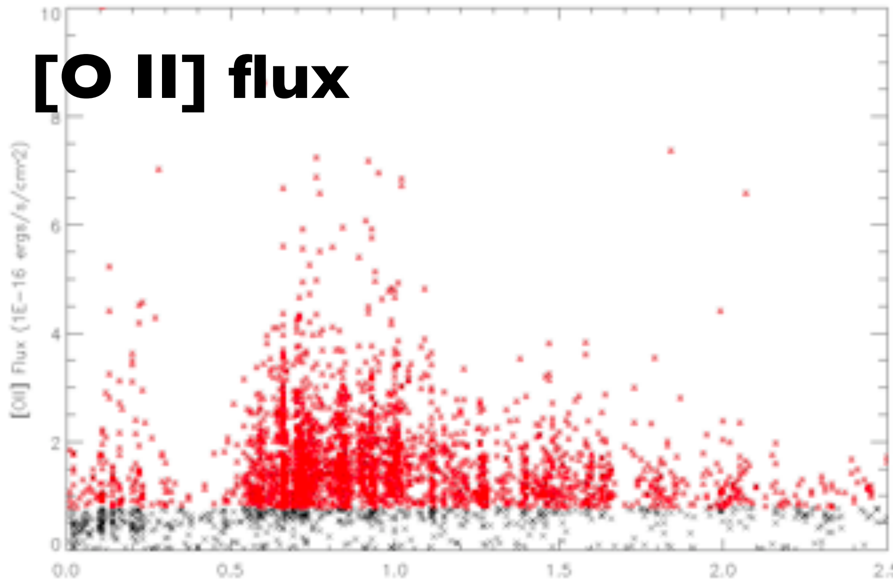
Select from PTF g+r+i bands

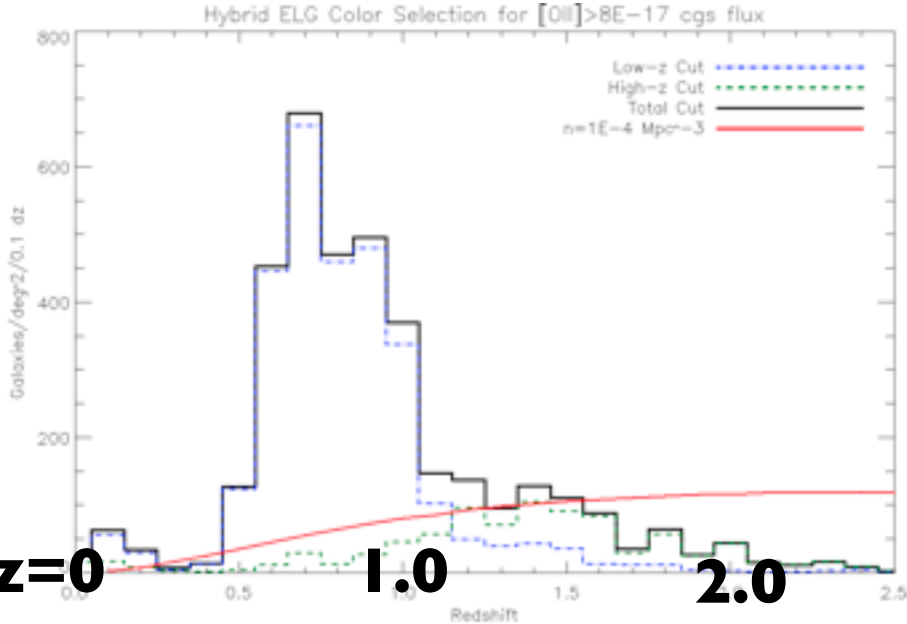
80% completeness, [OII]>0.8e-16

⇒ 50 million galaxies over 24,000 deg^2

Targets: Emission-line galaxies 0.7<z<2







BAO + RSD sample

Select from PTF g+r+i bands

Enhanced numbers z<1.2

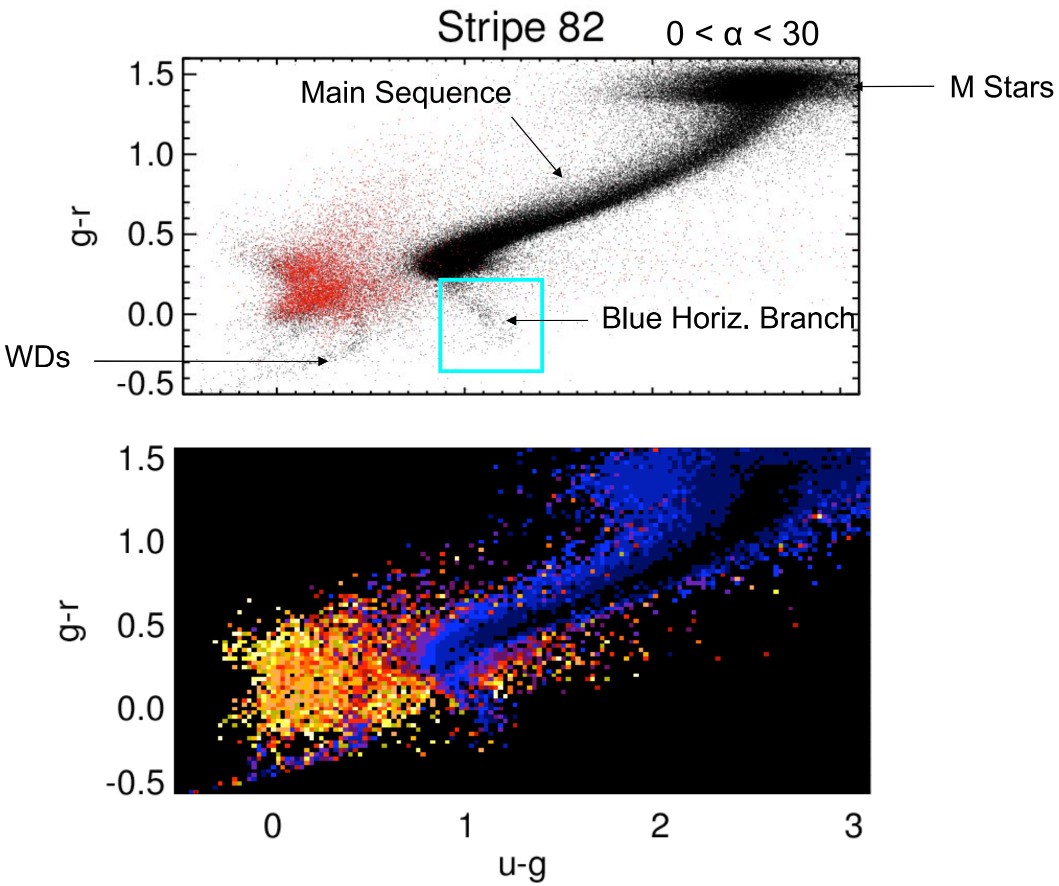
⇒ 80 million galaxies over 24,000 d

Other z-sculpting possible

http://bigboss.lbl.gov

Targets: QSOs

QSO targeting difficult for BOSS -- 50% stellar contamination
"Easy" for BigBOSS, with variability

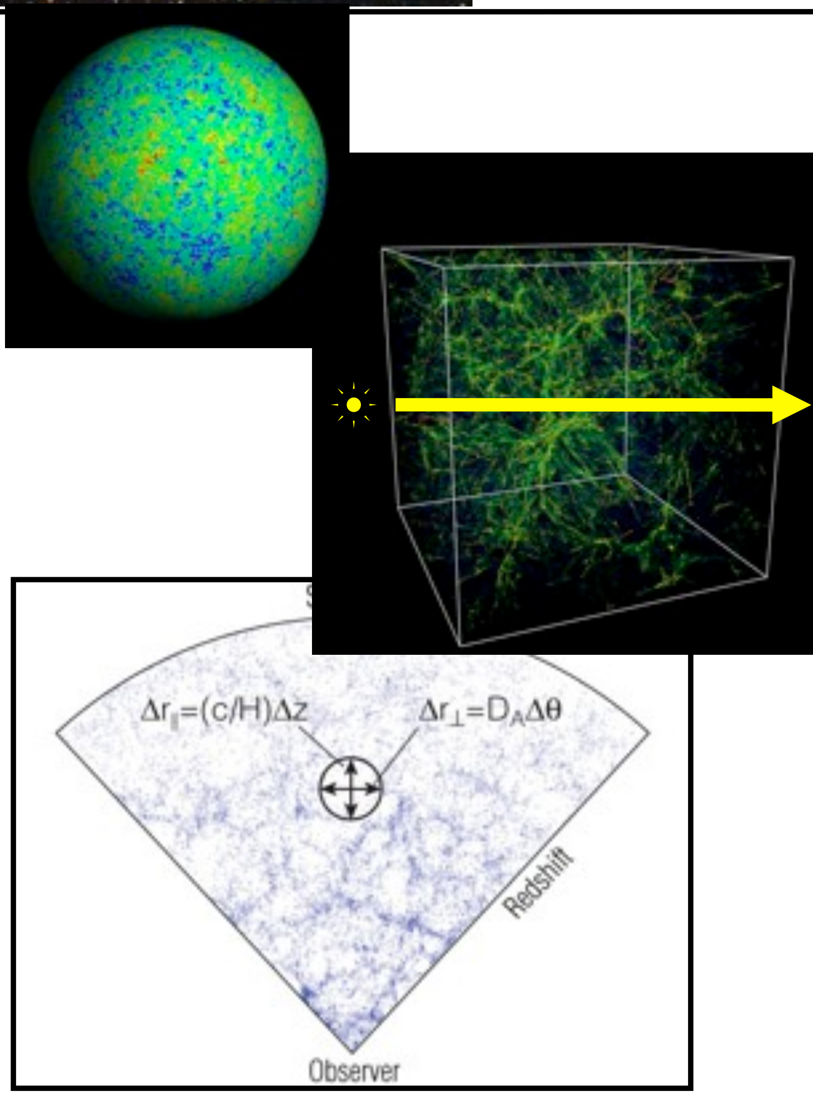


10

The Ground-Based Stage IV BAO Experiment

BigBOSS

Targets:
Re-optimize targets w/"extreme silicon"



z=1088

z=3.5

z=2

z=1.5

z=1

z=0

QSO LyA forest

Em. line galaxies

QSOs

LRGs

Low-bias **High-bias**

I. BigBOSS science

II. Pilot data: DEEP2

II. Instrument

III. Imaging + Targets

IV. Status

Status: Telescope call on Nov 18th

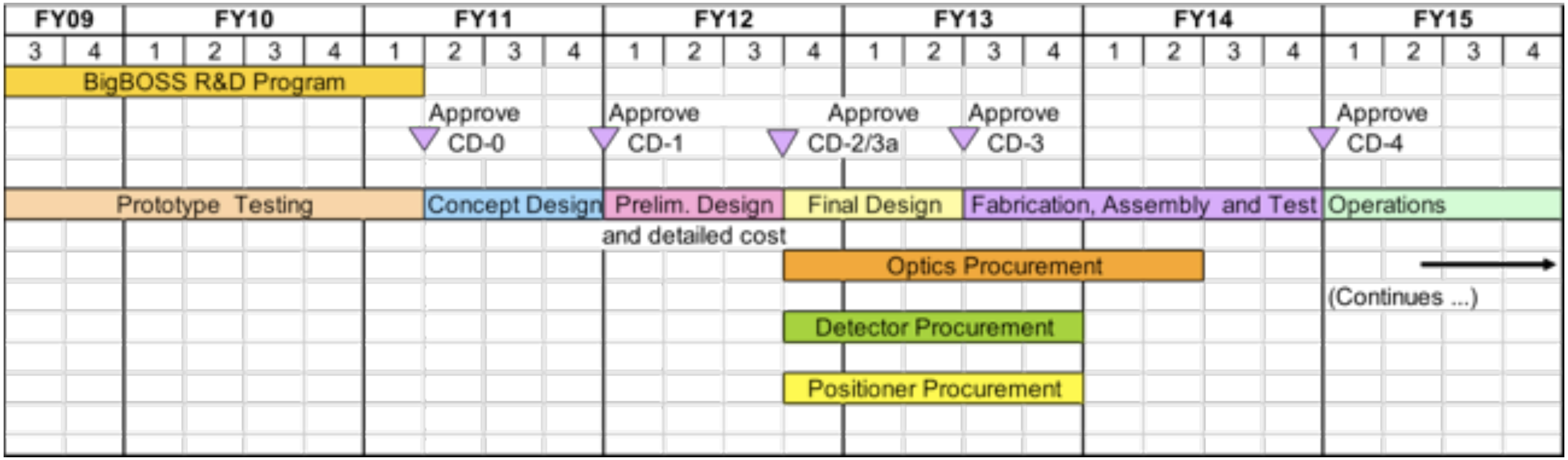
NOAO > KPNO Home

Announcement of Opportunity for Large Science Programs Providing New Observing Capabilities for the Mayall 4m Telescope on Kitt Peak

NOAO announces an opportunity to partner with NOAO and the National Science Foundation to pursue a large science program with the Mayall 4-meter telescope on Kitt Peak and to develop a major observing capability (instrument, software, and archival plans) for the Mayall 4-meter telescope of the Kitt Peak National Observatory for the purpose of enabling large, high impact science programs and improving the capabilities provided as part of the U.S. System of ground-based optical and near-IR telescopes. Projects that use a diverse range of observing requirements (e.g. time of year, lunar phase, etc.) are encouraged. The dual goals of the large science program, as discussed in a recent edition of NOAO Currents are to enable frontier science and to improve the U.S. system of ground-based ØIR facilities. Although there are no restrictions on the type or scale of instrument, NOAO encourages proposals that will build on the Mayall telescope's strengths, utilizing its unique wide-field capabilities. NOAO has investigated potential

Status: Budget & schedule

First light >=2015 at Kitt Peak



DOE PASAG report, Nov 2009:

"Substantial immediate support is recommended for BigBOSS R&D so that ground BAO possibilities are known for timely planning of a coherent ground-space dark energy effort."

Current R&D:

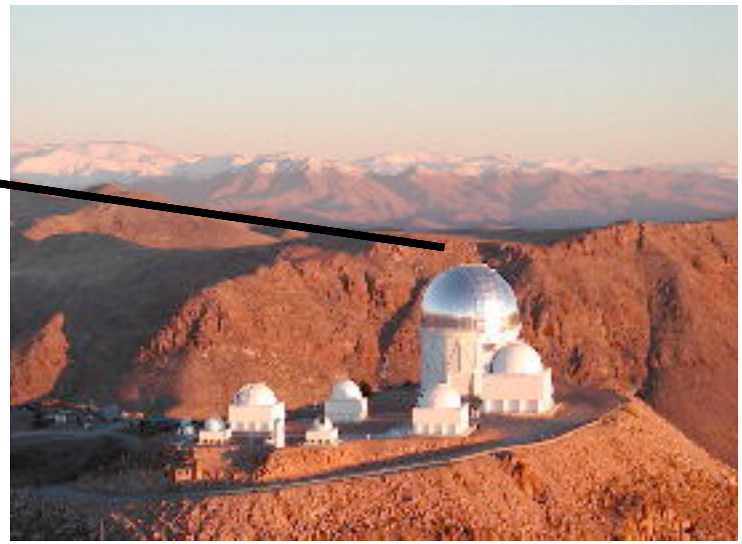
Fiber positioners (USTC/China)
Fibers (IEU/Korea)
Spectrographs, cyrogenics (Marseille + Saclay, France)
Extreme silicon (Berkeley Lab)

The Ground-Based Stage IV BAO Experiment
BigBOSS

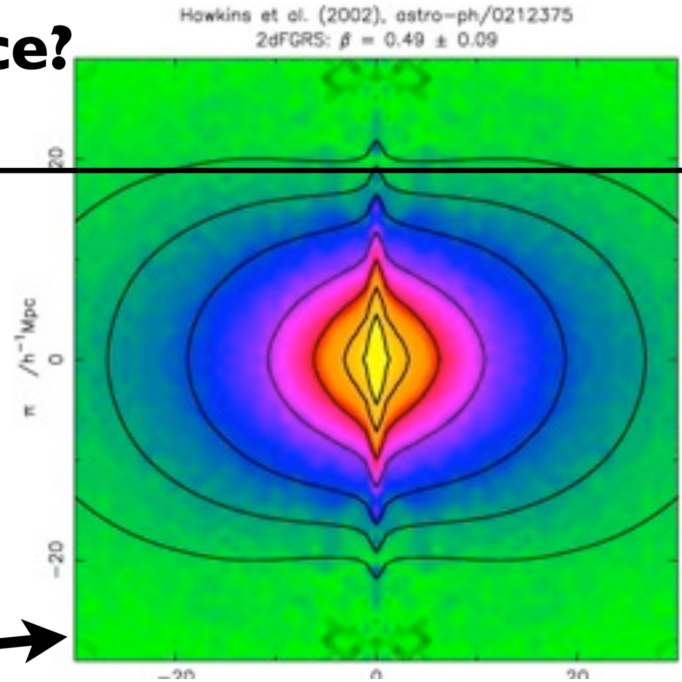
The Plan in >2020?

BigBOSS: Kitt Peak → CTIO
Complete full-sky survey

DES: CTIO → Kitt Peak
Northern complement to LSST

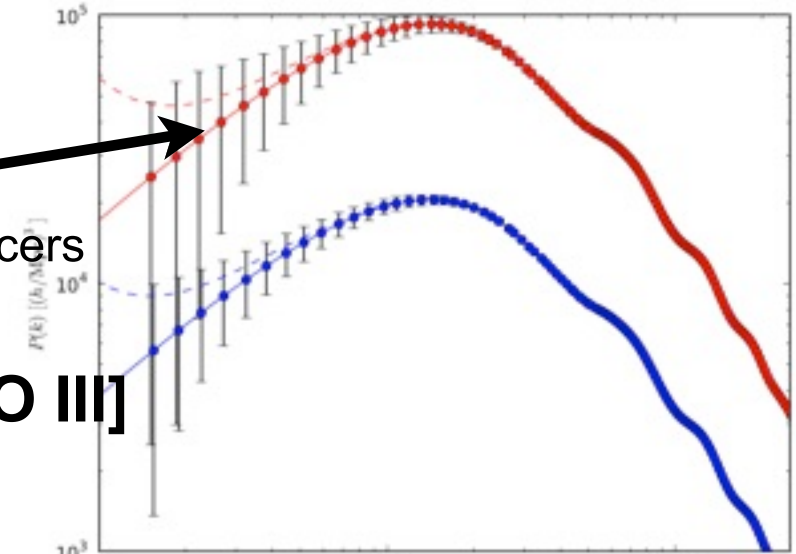


BigBOSS from space?



Space (EUCLID) difficulties

- ➯ **H-alpha lum. fn. uncertain**
  - [O II] well-studied
- ➯ **Grism spectroscopy uncertain**
  - Fiber-spectroscopy well-developed
- ➯ **RSD difficult**
- ➯ **Emission-line galaxies only**
  - No high-bias LRGs / multiple tracers
  - No systematics tests from multiple tracers
  - No Ly-a at z>2
- ➯ **Contamination from [O II], [O III]**



Question: Higher-order stats... difficult ground or space

Summary

- **"Stage-IV" dark energy experiment from the ground**
  - "BAO spectrograph" optimized for redshift-finding
    - 0 < z < 1.0 Luminous Red Galaxies
    - 0 < z < 1.7 Emission-line galaxies → 50 million in 10 years
    - 1 < z < 2 QSOs
    - 2 < z < 3.5 QSO LyA forest

- **Inflation Probe from Non-gaussinity**
  - More linear modes than CMB == higher sensitivity to non-gaussianity
  - Uses different-biased tracers

- **Requires only 4-m telescope time**
  - North: Kitt Peak (4m)
  - South: CTIO (4m)

Sensitivity to new physics scales as # of modes
Possible with BigBOSS, JDEM, SKA...